

STRATOSPHERIC OZONE DEPLETION

JOINT HEARING
BEFORE THE
SUBCOMMITTEES ON
HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND ENVIRONMENTAL PROTECTION
OF THE
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ENVIRONMENT AND PUBLIC WORKS
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STRATOSPHERIC OZONE DEPLETION

WEDNESDAY, MARCH 30, 1988

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEES ON HAZARDOUS WASTES AND TOXIC
SUBSTANCES AND ENVIRONMENTAL PROTECTION,
Washington, DC.

The subcommittees met, pursuant to notice, at 10:05 a.m., in room 406, Dirksen Senate Office Building, Hon. Max Baucus (chairman of the Subcommittee on Hazardous Wastes and Toxic Substances) presiding.

Present: Senators Baucus, Chafee, Stafford, Durenberger, Mitchell, Pressler, and Symms.

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator BAUCUS. The hearing will come to order.

The subject of today's hearing is generally to explore and develop the recent findings by NASA and others concerning the accelerated rate of depletion of upper atmosphere ozone.

Many people, in earlier years, have pointed to the problem. It is unfortunate that the Congress and one country has taken action to begin to reduce the production of chlorofluorocarbons and, therefore, begin to address the depletion of upper atmosphere ozone. Those countries who so far have ratified the Montreal Protocol are the United States and Mexico. Other countries have not.

Also, today, we are here to explore the recent decision by duPont to phase out its production of chlorofluorocarbons. I particularly commend duPont for taking that action. It is a major step toward solving a very severe, significant problem.

I suppose that duPont's action and the potential increased action on the parts of others, not only this committee, this Congress, but other countries is a result of recent findings from the ozone trends study. The results of this study indicate that the problem is much worse than we thought when we negotiated the Montreal Protocol, and even when this body enacted its actions. We assumed that there is an approximately one-half percent reduction in upper atmosphere ozone. It is turning out that, based upon the trends study, there is about a 2½ percent reduction in upper atmosphere ozone, and in northern latitudes it sometimes reaches over a 6 percent reduction. The point being that there is a reduction, there is depletion, and the rate of depletion of stratospheric ozone is much more than we earlier thought, that is, more than we thought when

we negotiated the Montreal Protocol, and more than we thought at the time this Congress took action.

So we are here today to develop, to better understand those new findings, what they mean. We are also here to explore the health and other effects of these findings. It is becoming more and more clear that the health effects of reduction of stratospheric ozone are very severe, not only cancer but other adverse effects on other organisms in the world. So it may be that we have to go further, that we have to reopen the Montreal Protocol and negotiate even further reductions in chlorofluorocarbons. That, too, will be a subject of today's hearing.

We will also look into substitutes that duPont and others might be able to develop, the cost of those substitutes, the toxicity of those substitutes, and other ways to find refrigerants and other materials that chlorofluorocarbons are presently so much involved with.

So, without any further ado, I want to thank the witnesses who are here today. I particularly want to thank Senator Bumpers, who has been in the forefront of this issue.

Senator Bumpers was a voice in the wilderness years ago. There were several voices in the wilderness years ago, but Senator Bumpers certainly was one. It is unfortunate that this Congress did not follow the lead of Senator Bumpers and other Senators who, years ago, pointed out the dire consequences of not only chlorofluorocarbon production and emission, but generally the reduction of stratospheric ozone.

Before we proceed to you, Senator, I would like to turn to other members of this panel who have been working very hard in trying to address this issue.

To my immediate right is Senator Chafee, one of those to whom I referred to as working hard to address the problem, and I want, at this time, to turn the hearing over to him.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator CHAFEE. Thank you, Mr. Chairman. I want to welcome Senator Bumpers also. Some wag today said, "There's good news and bad news. The good news is Dr. Rowland's been proven right, as we all thought. The bad news is it's much worse than we thought."

Most of the issues that come before this committee start with a sense of urgency, and certainly this ozone depletion problem is no exception. And what seems to me sets this issue apart is that things are happening at such an incredible rate. Our understanding of the problem is advancing so quickly that we are hard-pressed to respond quickly enough. We are on an emotional roller coaster. It seems that every bit of good news is followed just as quickly by bad news. One day we have the big signing in Montreal and a few weeks later we learn that the ozone hole over Antarctica is worse than anyone thought, and that the agreement apparently isn't tough enough.

One day we vote to approve the protocol, and the next day—and this was the very next day—an international panel of a hundred

scientists released a report telling us that the destruction of the ozone layer on a global scale is no longer just a theory, the hole over the Antarctica is no longer an isolated seasonal phenomenon.

Last week we had duPont endorsing the position: we had been advocating for quite some time, namely, reductions are not enough, it's time to eliminate these chemicals. This week we see preliminary data for 1987 showing that the U.S. production of CFCs grew in 1986, the last year we have data for, by 12 percent, which is a lot more than the three to five percent which was projected.

What do we do about this global disaster? It seems to me we have got to work on several fronts. First, we need to convince the rest of the world to ratify the Montreal Protocol. It's important to keep in mind the agreement does not take effect until it is ratified by 11 countries representing two-thirds of the world CFC production. And until that's done, we only have a piece of paper.

And so, to get ratification as quickly as possible, the United States and the United Nations Environmental Committee should take this new report and launch a massive diplomatic mission.

I want to pay tribute to the United States in this. Ambassador Benedict and Lee Thomas have both been terrific, as has our State Department in this whole matter, and I hope they'll keep it up and carry the message of alarm around the world.

Second, there is absolutely no reason to delay an emergency meeting of the parties to reassess the adequacy of the Montreal Protocol. The fact that the protocol calls for such a meeting in 1990 is not a sufficient reason to delay. The provision for a 1990 reassessment did not anticipate that such shocking new evidence would be upon us so quickly.

I am pleased to learn that Lee Thomas will be sending a letter later this week to Dr. Tolba, who we all know is UNEP's executive director and has done an excellent job. My hat's off to Dr. Tolba. Lee is going to suggest that the reassessment schedule be moved up. Several of us sent a similar letter to Dr. Tolba last November, and I plan to update our earlier letter to Dr. Tolba and will circulate it for signatures.

Finally, we have to be ready to impose new, more stringent, requirements in this country to eliminate the United States' contribution to the problem. Production controls alone will not suffice, especially if they do not go beyond 50 percent reduction.

Many people suggested that EPA's proposal to implement the protocol through allocated production quotas that stop at 50 percent will have several unintended effects. I don't know whether they will or not. We'll examine that today.

First, are we going to create huge windfall profits for the producers, those who get the quotas?

Second, will it create an incentive to delay introduction of substitute chemicals? I don't think so, but maybe.

And third, it will place small users in a price squeeze and a bidding war with other users.

Dupont's recent announcement that they intend to cease production of these harmful chemicals was extremely encouraging, and I would also like to commend, as you did, Mr. Chairman, duPont for what they've done.

And in a similar vein, Allied Signal announced yesterday that it was beginning a major new joint venture with a large French company to develop safe substitutes.

So, in closing, I just want to congratulate you, Mr. Chairman, for pressing on with these hearings. It seems to me this is something that we all have to give our constant attention to and be help in every way and press forward to see if we can't move this Montreal situation along in the reduction of the CFCs, not only nationally, but worldwide.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator.

Senator CHAFEE. And I want to commend you. You've been outstanding in this issue, and you've been one of the original pioneers in the area, and I'd like to thank you for that.

Senator BAUCUS. Thank you, Senator.

I would like to introduce the third original pioneer in this area, present this morning, a stalwart and a real leader, Senator Stafford.

**OPENING STATEMENT OF HON. ROBERT T. STAFFORD, U.S.
SENATOR FROM THE STATE OF VERMONT**

Senator STAFFORD. Thank you, Mr. Chairman. I am not going to repeat what you have said and what Senator Chafee has said, but I certainly agree with it and would, if it were possible, adopt your statement as my own as well.

I think I would be remiss, though, if I didn't say that I also am pleased with the position that the duPont Company took, and I hope that the other major manufacturers in this country and abroad will follow their example in this particular instance.

Finally, I really agree very much with the treaty that has been signed in Montreal. I join in the hope it will be ratified very quickly. I must say, though, that when Lee Thomas and our other representatives initiated the effort to get a treaty, that their original goal of a 95 percent reduction instead of a 50 percent reduction looks now like it was very much the proper course to follow, and I wish that we had been able to achieve that goal rather than the eventual 50 percent reduction.

Mr. Chairman, most of the attention this morning is going to focus on the way that freons and other CFCs have destroyed parts of the planet's ozone shield. That is their role in climate destruction, but these chemicals have another effect which may be just as important, and I would like to speak to it for just a second.

Last year was either the hottest, or tied for that distinction with 1981, in the history of this globe. Three of the years in this decade, 1981, 1983, and 1987 were the hottest since records have been kept. Last winter, that is, December 1987 and January and February of 1988, were the hottest on record as well. Perhaps this is merely a natural variability. After all, there have been hot years before, and even several hot years a row. But, whether or not this is the decade of the long-awaited signal that the hothouse Earth has finally arrived, scientists tell us that soon a fundamentally different Earth will be visited upon humanity.

Within a generation, the average temperature of the planet will have increased more than another half-degree centigrade. That will be the equivalent of having moved the Earth a million miles closer to the sun. They point to the western droughts, the disappearance of snow in the European Alps, the death of Caribbean coral, and a wide variety of other unexplained phenomena.

A major contributor to the climate destruction will be the freons and other CFCs. They presently account for about one-fifth of global heating due to man-made chemicals and activities. Had the United States not banned spray cans and other aerosol uses in the 1970's, CFCs by now would have overtaken carbon dioxide as the principal hothouse gas.

As we consider what actions are prudent this morning, and later, I believe it is important for us to bear these facts in mind. Eliminating these chemicals not only helps protect the ozone layer, assuming there is still time to do that, but gives added flexibility in dealing with climate variation.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator.

Before I proceed, I would like to make a suggestion. That is, that the President, at the next economic summit, press forward and press other countries at the next economic summit in Ottawa, to accelerate their actions to reduce chlorofluorocarbon production in the world, not only to ratify the treaty, but to press the other heads of state at the next economic summit to go further with, I frankly think, two specific goals. One is to immediately eliminate the frivolous use of the chlorofluorocarbons, and that's particularly with CFCs in aerosols, 27 percent of worldwide chlorofluorocarbon use is in this area. That use can be eliminated immediately. That's 27 percent. The second specific goal, I suggest the President press at the economic summit is for countries to set a definite timetable for a 95 percent reduction in chlorofluorocarbons. The President, at the last economic summit, suggested that the various countries present move forward. Now is the time, I think, for the President, based upon this new evidence, to be much more specific and much more firm. And I think, too, that we should do whatever we can to encourage other companies to follow the lead of duPont and begin to phase out and move toward substitutes.

If America can take the lead in ratifying the Montreal Protocol and if an American company can take the lead to begin to phase out production of CFCs, certainly other countries should follow suit and we can take the further lead in moving more expeditiously.

Senator Bumpers, we are glad to have you here.

STATEMENT OF HON. DALE BUMPERS, U.S. SENATOR FROM THE STATE OF ARKANSAS

Senator BUMPERS. Thank you very much, Mr. Chairman.

Mr. Chairman, members of the committee, thank you for allowing me to be with you this morning.

Let me start by just saying it's been 15 years ago now, this fall, since Professor Rowland and his research student, Mario Molina, put forward their dramatic proposal that CFCs were depleting the protective stratospheric ozone layer. And 2 years later, an inter-

agency task force on the Inadvertent Modification of the Stratosphere published a major report on what was known about depletion and its adverse effects on human health, agriculture and natural ecosystems. Then in September of 1975, Senator Domenici and I, then on the Space and Aeronautics Committee, held hearings on all aspects of this issue, and after listening to atmospheric and other scientists, industry representatives and government agency representatives during nine hearings, I became convinced that we were dealing with a problem that had the potential for major adverse consequences, not just for the United States, but for the entire planet.

Almost 12 years later now, we have reports on the Antarctic ozone hole, and the Ozone Trends Panel has just revealed how right we were then, and how belatedly we are reacting now.

Let me recount briefly some of the history of the ozone depletion issue, because I think it provides us with an important lesson about how we ought to respond to the immediate problem, but to the even more serious greenhouse effect issue, which we are being warned about by many of these same researchers. Senator Stafford has already alluded to that, and I am sure most of you have already seen the story in the New York Times yesterday which ought to be made a part of the record, Mr. Chairman.

Senator BAUCUS. Without objection.

[The article referred to follows:]

[From the New York Times, Mar. 29, 1988]

TEMPERATURE FOR WORLD RISES SHARPLY IN THE 1980's

SOME SCIENTISTS MAINTAIN THAT THEY ARE FINALLY SEEING RESULTS OF GREENHOUSE EFFECT

(By Philip Shabecoff)

WASHINGTON, March 28.—Average global temperatures in the 1980's are the highest measured since reliable records were first kept over 130 years ago, according to reports now coming in from scientists around the world.

Temperatures have been rising more or less steadily for much of the last century. But, in the view of some scientists, a sharper rise detected in the 1980's is the most persuasive evidence yet that carbon dioxide and other industrial gases are trapping heat in the atmosphere and warming the earth as if it were a greenhouse.

In interviews, meteorologists and others engaged in plotting global climate trends were cautious about blaming the greenhouse effect for the recent sharp increase, saying mathematical models of the phenomenon project much sharper increases than have so far occurred.

But several agreed that if the pattern persisted into the next decade, it would almost certainly mean that an era of global warming, caused by humans and certain to affect them in major ways, has begun.

How hot is the world now? The scientists do not offer a straightforward response, saying that the vast amount of data is still being studied and that comparisons cannot be precise. But the data gathered by American, British and Soviet scientific teams generally show a faster warming so far in the 1980's than in the century before. And most of the readings agree that the three or four warmest years on record occurred in this decade.

One of the scientists, Dr. James E. Hansen of the National Aeronautics and Space Administration's Institute for Space Studies in Manhattan, said he used the 30-year period 1950-1980, when the average global temperature was 59 degrees Fahrenheit, as a base to determine temperature variations. He said his readings showed that the average global temperature rose about as much since the base period as it did from the 1880's to the base period—about half a degree in both cases. He stressed that these were estimates and that it would take millions of measurements to reach an accurate global average.

Mathematical models project that at the current rate of buildup of the gases thought to cause the greenhouse effect, the average global temperature will rise from the 59-degree base by 3 to 9 degrees Fahrenheit by about 2030, with increases substantially greater at higher latitudes but lower increases near the Equator.

Dr. Hansen said the temperature was increasing in this decade even as natural factors were keeping surface temperatures lower than they might have been. These factors, he said, are relatively low radiation from the sun and high volcanic activity, which produces particles that tend to filter out some solar radiation.

As the earth warms, experts predict major changes in climatic patterns and a gradual rise in sea levels as the warming oceans expand and polar ice melts. Coastal flooding, dust bowls, sharply reduced crops, and dying forests could result in some regions. On the other hand, some relatively barren areas might become farmlands.

Tom Wigley, director of the Climatic Research Unit at the University of East Anglia in Britain, said that his data, taken for stations on the ocean as well as on land, found that 1987 was "the warmest year on record" and that the three warmest years in the record were 1987, 1983, and 1981.

He said in a telephone interview, that while some of his data supported the predictions of the greenhouse models, others did not. For one thing, he said, the temperature levels in the higher latitudes of the Northern Hemisphere did not rise as fast as the models predicted.

HARD TO DENY

But he said that if "the next 10 years are as warm or warmer, it would be very hard to deny the greenhouse effect," adding, "It is very hard to deny now."

"Chances are the greenhouse effect is not as strong as some people say, but you can't say it isn't happening at all," he said.

Both Dr. Wigley and Dr. Hansen said temperatures taken by Soviet scientists were similar to theirs.

Temperatures in the United States in this century did not rise as fast as global temperatures; several explanations are possible, including a different climate circulation over the country and pollution particles that block solar radiation. Still, measurements by the National Climatic Data Center of the National Oceanic and Atmospheric Administration show that the last few years were substantially warmer than any year since the 1950's in the United States.

Thomas Karl, research meteorologist for the center, said that 1986 and 1987 "were both unusually warm" in this country with a 54 degrees Fahrenheit for both years.

"Our data are not inconsistent with the greenhouse effect," Mr. Karl said, but "I am more cautious than others. I found you can get in a heap of trouble if you look at a climate time series and draw an inference. You can get swings that last for 10 or 20 years."

GRADUAL RISE SINCE 1800'S

Global temperatures had already shown a gradual rise since the late 1800's. The century-long warming trend is still considered a "real mystery," although the greenhouse effect is probably part of the answer, said Alan Hecht, director of the Federal office.

Dr. Hecht noted that the earth was now in the later stages for an interglacial period, meaning the temperatures should be growing cooler as a new ice age approached.

He said the amount of carbon dioxide in the atmosphere had risen from 280 parts per million to 340 parts per million over the last century, probably because of the burning of fossil fuels and the destruction of forests whose trees use carbon dioxide.

A LAG IN TEMPERATURE RISE

Given that increase of carbon dioxide, global temperatures should have increased by almost 2 degrees Fahrenheit over the century, under the assumptions of most of the models. But in fact they increased only about 1 degree, said Michael E. Schlesinger, associate professor of atmospheric sciences at Oregon State University.

One possible explanation, he said, is that "the models are more sensitive than nature." A more likely explanation, however, is a lag between the emission of greenhouse gases and the greenhouse effect because much of the extra heat is stored in the oceans rather than moving immediately to the atmosphere.

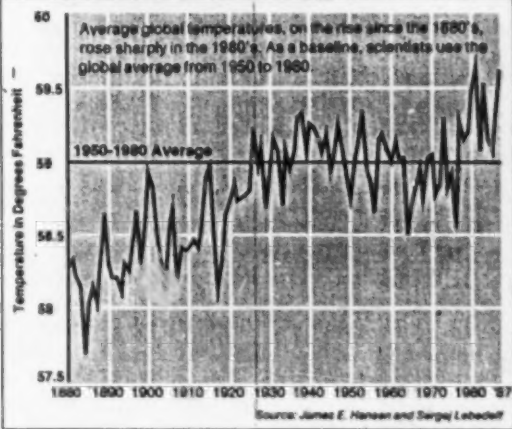
Dr. Schlesinger said testing the greenhouse models required not just taking readings of global temperatures but also plotting their geographical distribution. He said that he and colleagues were doing that now and that the results were so far mixed.

Meanwhile, human activity is sending carbon dioxide and other gases that trap radiation from the sun, including chlorofluorocarbons, methane and nitrous oxides, into the atmosphere at faster rates. If the models are correct, that means that global temperatures will rise sharply. Chlorofluorocarbons are also believed to be destroying the stratospheric ozone that shields the earth's surface from ultraviolet radiation from the sun.

Michael Oppenheimer, an atmospheric physicist with the Environmental Defense Fund, a group based in New York, said, "If the last few years are taken seriously it means the world is now warming very rapidly and, at the beginning of the next century, the climate warming will be the major environmental problem of the globe."

Global Warming Trend Accelerates in 1980's

Record Warmth in the 1980's



The New York Times/Mar. 26, 1988

Du Pont Sends a Message on Ozone

The Du Pont Company has pledged to phase out all production of CFC's, the chemicals that erode the life-protecting ozone layer in the high atmosphere. Du Pont, the world's largest producer of CFC's, with sales of \$600 million a year, set no specific timetable. But it said a "reasonable goal" would be to cut output by 95 percent by the year 2000 — nearly double the goal set by an international protocol last year.

The Du Pont action sets a compelling precedent for countries and companies still skeptical of the urgent need to develop alternatives to CFC's.

Du Pont has invested heavily in developing substitutes for CFC's. Still, the decision to phase out production must have been hard. The chemicals have many uses, as refrigerants and solvents, in auto air-conditioners and foam packaging, and account for 2 percent of the company's earnings.

CFC's are largely benign and non-toxic. But their very stability is what makes them a threat. Unlike other chemicals, they resist change as they percolate up through the atmosphere. As they are destroyed by sunlight they release their chlorine atoms, each of which destroys about 100,000 molecules of ozone.

Ozone fluctuates widely in response to solar ac-

tivity. But beyond such natural gains and losses, the ozone layer is also being destroyed by chlorine. The reduction attributable to chlorine since 1960 is as much as 3 percent. For every 1 percent thinning in the ozone layer, some 2 to 3 percent more ultraviolet light streams through. That causes biologists deep concern. Damage to plants and animals could quickly affect the environment, food chains and human health.

Also at risk is the comfortable assumption that the atmosphere is so large and complex it will respond very gradually to man-made changes. The recently discovered "ozone hole" over the Antarctic each September is air that has lost 50 percent of its ozone. There was no hole in the 1960's when the chlorine in the high atmosphere amounted to one part per billion. The hole appeared after chlorine levels increased to the present level of just 3 parts per billion. This suggests that the atmosphere is in fact vulnerable to small changes.

A pending international treaty, the Montreal protocol, calls for a freeze in global CFC production, followed by a cut of only 50 percent. Du Pont's actions signal the need to take even bolder steps to correct an extraordinary imbalance in the earth's protective canopy.

Senator BUMPERS. If we wait 12 years to deal with this problem, the delay may be much more devastating than just ozone depletion.

But back to the chronology. By the mid-1970's, atmospheric scientists such as Rowland, Cicerone, McElroy, Anderson and others had compiled impressive data suggesting, but not proving, the CFC-ozone depletion link. Their relatively simple models predicted ozone depletion levels in the 5 to 10 percent range if we continued to release CFCs at then current rates. There were uncertainties in the models, gaps in our knowledge of stratospheric chemistry and a shortage of actual measurements of stratospheric chemical species. It was clear that it would be nice to improve our scientific understanding, but it was also clear that waiting to gather the information needed to convince everybody was courting disaster. CFC production was doubling every decade and that's just about the minimum time for CFCs to diffuse up to the stratosphere where they destroy ozone.

So we did what all good politicians do: we waited, we waited until we saw a detectable decrease in ozone. At that time it was felt that the smallest detectable loss was 5 percent, which meant we were faced with twice that amount from chemicals already in the atmosphere if we stopped releasing CFCs at that moment. Even a five percent decrease was, in my judgment, unacceptable.

Unable to respond fully to the problem because of strong industry opposition, the Congress in 1976 passed the usual political compromise. We increased funding for research which we promptly reduced again in the 1980's just when it was needed most. Those cut-backs cost us a great amount of time, during which millions of tons of extra CFCs were released into the atmosphere.

Secondly, we knew that 62 percent of the CFCs were used in aerosol sprays, so we passed amendments to the Clean Air Act that phased out those uses. Despite Senator Packwood's and my best efforts, only 28 senators, 28, voted in favor of our 1976 amendment to halt the use of CFCs in aerosols by January 1, 1978.

Mr. Chairman, I might also add that the hallway just outside the Senate was so full of lobbyists from the chemical industry you could hardly fight your way in to vote. And while I, too, applaud what duPont has just done, they had their share of industry representatives outside the Senate at that time, too. Instead, we had to wait for the bureaucratic process, and fortunately the FDA Commissioner, Dr. Schmidt, ruled that the risks were just too great for us to continue using CFCs in aerosols. It was too dangerous to wait for definitive proof.

Most of us thought we had bought a little insurance and a little time to develop substitutes by banning the non-essential uses of CFCs in aerosols. Unfortunately, only Canada and a few Scandinavian countries followed suit and joined our ban on aerosols.

By 1980, duPont announced that it was no longer pursuing alternatives to CFCs, despite its assurances in the 1970's that it was using this time to develop substitutes. And what about the science? Although we put up a couple of satellite experiments, we generally allowed research funding to decline until the next crisis erupted in 1985 with the dramatic discovery of the Antarctic ozone hole. My own worst fears were confirmed.

So here we are today faced with the disappearance of over half the column of ozone over Antarctica each October, a condition which lasts longer each year. These massive losses and their sudden onset at the end of the 1970's make a mockery of our debates in 1976 on the Packwood-Bumpers amendment, as to whether there would be a three percent or a seven percent decrease in ozone CFCs. The impressive correlation between ozone depletion and the presence of chlorine in the stratosphere that was documented by Professor Anderson last fall leaves no doubt as to the role played by CFCs. You will hear more about the scientific data of these findings from Professor Rowland, plus a dissertation on the devastating effects on the food chain of the southern oceans from Professor El-Sayed.

The Antarctic ozone hole is a dramatic event for which there is no known remedy, and which will require more than a century to heal even if we stop all releases at this moment. Of even greater concern for us is the evidence of global decreases in ozone that affect human populations directly. What is troubling about the decreases reported by the NASA coordinated Ozone Trends Panel is that they exceed predictions by substantial margins. Dr. Watson will fill us in on the grim details later this morning, but I would like to suggest that these data only confirm the direction we knew we were headed in 12 years ago.

The tragedy is that, despite the fine work done by Senator Baucus and the members of this committee, despite the careful negotiations at Montreal, and the successful ratification of the protocol last week, and despite duPont's dramatic and laudable announcement to phase out the production of CFCs, we are now where we should have been a decade ago. Had we acted then rather than reacting now, we would be completing the transition to new technology today rather than just beginning it.

While we cannot undue the damage already suffered by the upper atmosphere, or prevent the additional harm that is yet to come to human health, agriculture and the natural world, there are some actions that we can and must take. Although the action we took had a dramatic effect in reducing worldwide aerosol use from 63 percent to 37 percent today, other uses were expanded and we are now back at historically high production levels. The Montreal Protocol would reduce production to half the 1986 levels by 1999, but because of the drawn-out implementation time, chlorine levels will increase to twice their already unacceptable levels.

Mr. Chairman, we must deal with this problem rapidly and effectively. I don't have a comprehensive proposal, but I suggest that the following action be taken immediately.

To date, only Mexico and the United States have ratified the Montreal Protocol to limit CFCs. As weak as this protocol is, it is an important first step. The Senate should press its parliamentary colleagues in Europe, Japan, and the USSR to move quickly to ratify the treaty. Then they should urge Dr. Tolba, the director of UNEP, to reconvene the parties within six months from now to reconsider a more rapid phase-out. A letter signed by 100 Senators would help move other nations forward, and I hope the chairman and other members of this committee will join me in circulating such a letter to be mailed before we leave here Friday.

The upcoming economic seven-nation summit will also be an ideal forum in which the President could press our economic partners. The Chairman has already alluded to this.

Number two: To implement the Montreal Protocol, EPA is proposing a system of free rights to CFC producers on a percentage basis of their 1986 market share. This policy will slow the introduction of alternatives. A high fee of five to ten times the current price of fifty cents to a dollar per pound would not only encourage alternatives but would promote conservation and reuse of CFCs during the transition period. A bill that would accomplish this goal has been introduced in the House and similar bills are before this committee for the Senate. We should hammer out the differences and act on those bills immediately.

Number three: We ought to impose a near-term ban on non-essential uses of CFCs, and the use of CFCs on non-essential things such as styrofoam food packaging, and cups, open foam blowing and the flushing of automobile and home air conditioners ought to be discontinued very quickly.

Fourthly, we should fund our share of international programs such as those of the World Meteorological Organization, the United Nations Environmental Programme, under whose auspices the Montreal Protocol was negotiated, and the International Geosphere, Biosphere Programme. We haven't funded these programs fully in the past, but we must meet our international obligations in the future to solve a global problem.

And finally, and this is not a recommendation, we wouldn't even be aware of this problem had not scientists like Professor Rowland and others persevered even when the Federal agencies and the Congress short-changed them in terms of research funds. I personally want to thank Professor Rowland for his work and for his patience. And I know that he has often been subjected to unwarranted criticism and personal attacks.

We cannot expect scientists like him to be around when we need them unless we are willing to support not only research, but the training and support of the next generation of scientists in what is coming to be known as earth system science.

I recognize that there are budget constraints, but we must reallocate our priorities to raise the mission of saving Planet Earth above the Manned Mission to Mars, the hypersonic airplane, or the supercollider. We must examine programs at NASA, NOAA, NSF, DOD, EPA, and other agencies to be certain that these global problems are being adequately addressed. I plan to do all I can to shift research priorities to the study of global change issues, when we work out the appropriations process this fall. And I urge the support of the members of this committee.

Finally, I can only hope that we have learned a valuable lesson from all this. If we have not, we are facing an even more ominous threat—the threat of global climate change arising from the greenhouse effect. Once again, scientists are in agreement that the effect is real and that the consequences of altered weather patterns and rising sea levels will exceed anything the earth has seen in the past 100,000 years. If timid politicians again refuse to face this dramatic problem head-on, we will pay a staggering price, and stand fairly accused of gross negligence by future generations. If we

commit ourselves to say a 30-year project to study this issue and monitor the results, we may reverse the problem. A Global Change 2020 Program could also alert us to other issues that have not yet even occurred to us. We must begin now to change those activities that involve both the greenhouse effect and a host of other interrelated issues. We can also begin to act now to reduce the more serious consequences of the greenhouse effect. While carbon dioxide from burning fossil fuels is responsible for half of global warming, CFCs contribute 15 to 20 percent of the projected global warming. The problems of ozone depletion and global warming are interrelated. Will the proposed CFC substitutes, designed to reduce ozone depletion, increase or decrease the greenhouse effect? Improving energy efficiency, as this Congress did last year with appliance standards, will slow greenhouse warming, improve our energy security and economic competitiveness, and reduce acid rain. Developing renewable energy resources will accomplish those same goals. Promoting reforestation will not only reduce the buildup of carbon dioxide, it will prevent erosion and loss of biological diversity, as well as provide renewable resources.

In both ozone depletion and the greenhouse theory, we clearly face problems of global dimension that will affect all nations on a scale that has never been encountered in human history. The encouraging fact is that there is something we can do about it. It is also clear, however, that we must begin acting now to slow the growth of the emissions of greenhouse gases. Let us not repeat the mistakes of the last 12 years by not acting now in time to slow it up.

Waiting until a clear greenhouse fingerprint is unequivocally proven will, if current models are correct, commit us to substantial additional warming. These same studies also show that by taking action of the kind described here, we can reduce future warming significantly. By a prudent choice of policies that simultaneously slow the release of greenhouse gases and help solve other problems, we can effectively and prudently buy ourselves some insurance against a rapid global warming and its destructive consequences. It is both an exciting opportunity and a challenge for Congress to determine the policies that will determine our future.

Mr. Chairman, just in a little self-serving statement, the last paragraph of my barn-burning dynamite speech in 1976, on behalf of the Packwood-Bumpers Amendment was, there's a time bomb ticking up there and we can't afford to wait. If we are to err, we must err on the side of caution. And that same statement holds true today.

Thank you, Mr. Chairman and members of the committee.

Senator BAUCUS. Thank you, Senator, for an excellent statement. Not only is it comprehensive in its exposition of the problem, but a call to action, and also listing various specific, concrete steps that we can take and should take later, and we thank you very much for your contribution.

Senator Durenberger has joined us and is also very active in this area.

Senator, do you have a statement?

Senator DURENBERGER. I have no formal statement, Mr. Chairman, but let me take the occasion to compliment our colleague

from Arkansas, not just from what we have come to expect from him, which is leadership, but from the comprehensive way in which that statement has captured all of my limited experiences in this area.

I think my first exposure came in either 1979 or 1980, when Abe Ribicoff, whom we all remember as the outstanding Chair of the Governmental Affairs Committee, took us into a special—I think it was a two- or three-day set of hearings, in which he brought people in from all over the world to talk about the greenhouse effect and a variety of these issues. And I kept wondering what's this got to do with this particular committee that is supposed to be looking at the structure and operation of government. And it occurred to me that probably there wasn't anything more important that we, as legislators, do than to try to push out the horizon for those who are expected, in this area, to help us who have the responsibility of making public policy with information that we always lack.

I particularly appreciated your comments about earth science and some of the basic sciences in this country. It is a frustration to live in an environment that, somehow or other, enterprise will provide all the research and development we need in America, and that universities that concentrate their efforts on helping that rare combination of basic research and education can somehow scratch up the dough from here and there that is so vital to the protection of this planet.

So I, having chaired the subcommittee for three or four years, I think, and having dealt with this issue with a lot of our colleagues, Al Gore comes to mind as somebody who really has committed a large part of his efforts to this area. I am grateful to Max and everyone who has gotten us to spend this time on the subject.

Senator BAUCUS. Senator Chafee.

Senator CHAFEE. Mr. Chairman, I just want to say that I was very proud when I went to Europe last fall to find that the United States had banned the aerosol cans so long ago, and the discouraging side of it was that the Europeans haven't followed, and they've some complicated reason that the substitutes are very hazardous, and their factories are all somehow located right downtown and therefore they're all going to explode and kill a lot of people if they switched to aerosol, a very complicated reasoning.

I never quite knew how we got to ban aerosols, it was before I came, but it was apparently due to the work that you and Senator Packwood did.

Senator BUMPERS. It was done administratively, Senator. The amendment passed by Congress directed the FDA to study the use of aerosols and to make a determination whether or not to ban them.

Senator CHAFEE. Well, whoever did it, it was a big step forward, and I don't know why the Europeans—maybe they think we've carried the load, so why bother. That, of course, is one of the problems we are going to face today. The more we do the less they think they have to do. Maybe our recommendation should come out that we'll move ahead despite lack of international progress, and then have some kind of tariffs or quotas or ban on imports of any materials that contain CFC. Obviously, this committee has been through

this before and we'd like to move on an international grouping, all of us together, if possible.

But, if the others aren't going to follow, then it may be up to us.

Thank you, Mr. Chairman.

Senator BAUCUS. Senator Stafford.

Senator STAFFORD. I have no questions. I want to compliment the Senator on his very able statement, and I remember the 1975, 1976, 1977 era when we were trying to amend the Clean Air Act and did amend it, and it's too bad we weren't able to do something about CFCs at that time.

Senator BAUCUS. Thank you, Senator.

Senator BUMPERS. Mr. Chairman, thank you very much.

Senator BAUCUS. Senator Pressler was unable to attend the hearing today, his statement will be made a part of the record.

[Senator Pressler's statement follows:]

OPENING STATEMENT OF HON. LARRY PRESSLER, U.S. SENATOR FROM THE STATE OF
SOUTH DAKOTA

Mr. Chairman, I commend you for scheduling this timely hearing on the stratospheric ozone. There have been several recent developments in this area which this hearing will focus on.

The release of the Ozone Trends Panel report, the recent announcement by du Pont, and the ratification of the Montreal Protocol have changed the climate surrounding this issue. Unfortunately, the problem remains basically the same. How do we develop alternatives to CFC and phase out the use of CFC's globally. Negotiation and ratification of the Montreal Protocol was an important step in effectively addressing the ozone issue. One nation cannot solve this problem alone. All nations must work in a coordinated fashion. If the science clearly demonstrates the need for further actions, I would hope the United States again initiates international negotiations on this matter. For example, we might be able to negotiate an earlier phase out of CFC's in products, which there is currently an alternative available. We cannot solve this problem alone and unilateral action will take pressure off other nations to take appropriate action. International action is essential in this area and the United States should take a leading role in these negotiations.

Mr. Chairman I look forward to hearing today's testimony.

Senator BAUCUS. I would like now to call our first panel, Dr. Fred Urbach, Skin and Cancer Hospital, Temple University; Dr. F. Sherwood Rowland, Department of Chemistry, University of California, Irvine; Dr. Robert Watson, NASA Headquarters, Washington, D.C.; and Dr. Sayed El Sayed, College of Geo-Sciences, Texas A&M University.

Dr. Urbach, since we called you first, why don't you begin.

STATEMENT OF DR. FRED URBACH, SKIN AND CANCER
HOSPITAL, TEMPLE UNIVERSITY

Dr. URBACH. Thank you, Mr. Chairman, and members of the committee.

My interest and that of my colleagues for over 25 years has been to try to sort out the relationship of ultraviolet radiation to malignancies of the skin. We actually started measuring ultraviolet radiation with the very first of the prototypes of the meters that we recently reported on in 1963. At that time we had only one meter. We measured with the same meter for a year in Brisbane, a year in Philadelphia, and a year in Galway, and were able to collect skin cancer statistics at those areas. This was the first time we were able to definitively show not only, that ultraviolet radiation

was related to skin cancer, but to begin to get some semiquantitative idea how it is related.

Since then there has been a tremendous information explosion on such matters as action spectre and effects on DNA and cell membranes, and immunity. The important part to remember is that it is a very small part of the solar ultraviolet radiation that is related to all these biologic effects. This has been called UVB, wavelengths shorter than 320 nanometers. This makes up something like 5 percent of the total ultraviolet radiation and a very small part of the total solar radiation.

It also happens to be exactly in the place where ozone starts to absorb strongly, and it is because of the ozone layer in the stratosphere that wavelengths much shorter than 290 or so nanometers, which would be extremely injurious, do reach us. The great concern with reduction in ozone is that it is protective in that it absorbs the part of the ultraviolet radiation which is the one that is primarily responsible, not just for skin cancer, but also for injury to plants, plankton, and animals.

The interesting thing to me always has been how it is that plants and plankton and similar living materials survive, in Miami at noon. If a person would lie down from sunrise to sunset, one would get something like 33 sunburn units, which would be enough to be found the next day in a hospital, totally blistered and probably near death. Plants do this very nicely and they do this by various reasons, by protection, and particularly because they have very great repair systems.

A significant number of very important studies on the effect of ultraviolet radiation on living matter were performed under sponsorship of the Climatic Impact Assessment Program, of the Department of Transportation. Senator Bumpers is quite right, that this was presented in testimony in 1975. Everybody gave us lip service. I had the opportunity to testify before Senator Bumper's committee in the 1970's. Everybody told us "that's wonderful but we have no problem." All support for such studies stopped abruptly.

There was a great deal of work done at that time, and it was shown indeed that, for instance, if you protected plants that normally grow very nicely in the Alps from the local ultraviolet radiation, they grew much better. Professor El Sayed will show you similar things.

Let me get back to skin cancer, because that is my particular interest. There is now no question that the majority, virtually all non-melanoma skin cancers are due to chronic exposure to ultraviolet radiation. The relationship is such that if everybody lived 250 years, everybody would get skin cancer. The reason why some of us do not is because we have somewhat less exposure and we have a competing risk, we die before we get old enough to develop skin cancer.

And, as a matter of fact, that can be shown. The Irish, the Scot, and the Welsh, for genetic reasons are unable to tan. They freckle out sunburn and they have nice blue eyes, like Senator Baucus.

Dr. URBACH. They suntan poorly and get into all kinds of trouble. When in my tumor clinic I first started looking into this I assumed they would have more skin cancers. I found out they didn't have more, what happened was that they got them 20 years earlier.

In February, we reported that over the last ten years in eight places in the U.S., there was no increase in ground level ultraviolet radiation. There was a drop, but basically no change.

There are a number of reasons for this. You are, of course, aware that a decrease in stratospheric ozone has been reported recently. It has been said that the lack of response of our meters was because they were near big cities. Of course, that is true. They were placed there in order to support the skin cancer incidence studies performed by the National Cancer Institute.

However, we also have a meter on top of Mauna Loa, at about 13,500 feet that has also shown no change. There also has been an increase in tropospheric ozone. There was a lovely paper in *Nature* two days ago. In France where they dug up records from Paris of 36 years worth of tropospheric ozone and with present methods showed a 100% increase at ground level. Our meters are more affected by local cloud and environmental changes than Dobson meters. So I am not surprised that with the kind of changes of the ozone column that has been reported that we did not see much. Also, because the major ozone changes are in the winter, where there is a lot less biologically effective ultraviolet radiation than in the summer, it would be less likely for us to note small changes. This, however, does not mean that I am not concerned.

Senator BAUCUS. Would you summarize your concern, please?

Dr. URBACH. Yes. The concern, of course, is that if the ozone layer continues to decrease, which is reason able to suspect, ultraviolet radiation will without a doubt, increase and there will be a significant increase in all kinds of damage, skin cancer, plant damage, et cetera. The simple fact that we have not so far measured an increase only means that there are local tropospheric phenomena that do interfere with ultraviolet radiation that do not particularly interfere with measurements, such as those performed with Dobson meters. So there is great concern.

Senator BAUCUS. Thank you very much.

Our next witness will be Dr. F. Sherwood Rowland.

Dr. Rowland.

STATEMENT OF DR. SHERWOOD ROWLAND, DEPARTMENT OF CHEMISTRY, UNIVERSITY OF CALIFORNIA, IRVINE

Dr. ROWLAND. Yes. Both Bob Watson, who chaired the NASA Ozone Trends Panel, and I are going to be talking to some extent about the results of that ozone panel, and I believe Bob is going to talk in some detail about Antarctic ozone.

I am going to summarize my testimony by saying that there are three geographical regions where one expects ozone loss or has observed ozone loss. The first of these is in the vertical column. Since 1974, the expectation has been that the chlorine chemical chain operating in tropic and temperate zone latitudes should deplete ozone preferentially at altitudes around 40 kilometers. The investigations by the Ozone Trends Panel looked at two different sources of measurement there, one from satellite, especially the SAGE satellite, and the other by a ground-based technique called Umkehr. Both of these tend to show losses of ozone in the 40 kilometer region. At

the limits of their error bars, they are in modest agreement, and the theoretical expectation is also more or less the same as that.

We would like more accuracy on both the theory and on the measurements at those altitudes, but the indication is that ozone is being lost at the 40 kilometer altitude in the temperate and tropic zones.

And then there is the massive loss of ozone that has been observed over Antarctica, which I will leave for discussion to Bob Watson.

The third area of concern by the Ozone Trends Panel has been with the question of whether the long-term ground-based measurements, mostly with the Dobson instrument, have shown any change in ozone over the time period of measurement. This time period of measurement begins with a few stations, particularly Arosa, Switzerland, which has a continuous record since August of 1931, but there are a number of stations which have records that start in the late 1950's and especially in the early 1960's for the U.S. stations. Examination of that data in the Ozone Trends Panel has emphasized looking at the data on a month-by-month basis rather than just in yearly averages. When you look at it on a month-by-month basis, there is a distinct loss of ozone in the winter months for the latitudes north of 30 degrees, especially so in the latitudes north of 40 degrees or 50 degrees.

The indication that the ozone loss is not uniform over the year has some implications about the mechanisms of such loss. The calculations that were done up until very recently have tended to be performed with what are called one-dimensional models, and those don't provide information about seasonal differences, or even latitudinal differences.

In the two-dimensional models that are now being used, one can try to calculate losses of ozone both as season and as latitude vary. In the current theoretical models, there is reasonable agreement in the summer that the amount of ozone which is being seen is about—the decrease in ozone is about that which the theories have called for. But in the winter, there seems to be substantially more ozone loss than one can account for by current theory.

It should also be commented upon, and I think Bob will probably mention this, too, that the current theory is unable to explain in a quantitative way the loss of ozone over Antarctica. What we know is that there is something missing. We also know what it is that is missing, and that is how to put into the models the heterogeneous chemistry that's going on on the surfaces of clouds. The problem is putting those chemical reactions quantitatively into the models.

Therefore, we have theoretical ozone models which are defective for Antarctica and seem to be defective also in the northern hemisphere winter.

Any prediction as to what future changes in ozone will occur seems highly uncertain at the present time. If the model won't handle present chemistry, then what will it do for the future? The answer is, I think it is completely uncertain.

We turn to the question of the ozone protocol. The ozone protocol calls for the reduction in chlorine emissions to start in 1994 at a 20 percent reduction, and then an additional 30 percent reduction in 1999. In my testimony, I have shown a graph of what that means.

We were at about 1.8 parts per billion of atmospheric chlorine in 1974. We're in the vicinity of 3.5 parts per billion of chlorine in 1988. We will be around 5 parts per billion of chlorine in the year 2000 with or without the protocol. And I should add that, in the calculations that are shown in my testimony, I've taken the conservative point of view. There are three exceptions, all of which will allow more chlorine to go in into the atmosphere than shown in the testimony. One of them is that—the protocol doesn't take effect until 1990, and in 1987, 1988, 1989 the amounts of chlorine that will go in are probably greater than in 1986.

Then there is room for the Soviet Union to expand their production through 1990, and there is room for the developing countries to expand their production for ten years. So that the figures that I've shown that say 5 parts per billion of chlorine at the end of the century with the protocol are, if anything, underestimates of what might be present.

Clearly, the protocol is not going to cut into emissions, it's not going to do very much of anything in the next ten years, and I think that we need more rapid action than that.

When I was asked in the West German Parliament, about three weeks ago, what would it do to take the stratospheric content in chlorine back to what it was in the 1960's, my answer was, "An immediate ban on all release of chlorine to the atmosphere, and wait 200 years." Actually, if you look at the figures that I have in the testimony, I underestimated it. It will be more like three or four or five hundred years to get back to the 1960's.

Thank you.

Senator BAUCUS. Thank you very much, Dr. Rowland, for that excellent statement.

Dr. Watson.

STATEMENT OF DR. ROBERT T. WATSON, OFFICE OF SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. WATSON. Thank you, Senator.

What I would like to do is just to summarize a few differences between the status of science before we signed the Montreal Protocol and the status of science today.

Before we signed the Montreal Protocol we were quite concerned that the atmospheric concentration of a large number of trace gases, carbon dioxide, methane, nitrous oxide, and the fluorocarbons, were all increasing at an unprecedented rate due to human activities. The increases of these gases would cause changes in ozone and would have a significant modification to the climate system. We still believe that.

The rates of increases of these gases in the atmosphere continue unabated at significant levels.

When we went to Montreal, we were primarily trying to have a control measure that would safeguard the future of ozone, based primarily on a theoretical understanding. We predicted that with a global freeze of fluorocarbons it would only be of the order of one to two percent loss of ozone globally over the next century. It may be slightly higher levels at high latitudes. But at that stage, we ba-

sically stated to you, there were no observable changes in ozone since 1970. There was no change of ozone globally.

We also said there was an Antarctica ozone hole, but we didn't understand what caused it. Well, today we can make several strong statements.

As Dr. Sherry Rowland has just pointed out, there are observable changes at mid-latitudes since 1970. We tried to account for all known natural fluctuations in ozone, and the trend that was left, 1.7 to 3 percent in the global average, 2.3 to 6.2 percent in wintertime, cannot be attributed to any known fluctuations in solar cycle, changes in the local meteorology called the quasi-biennial oscillation. We cannot account for that on the El Chichon or the El Nino. Therefore, the conclusion of the report is those changes have to be either partly or wholly due to fluorocarbons.

In addition, in Antarctica, we now think we understand to a first approximation what is going on. The ozone hole is no longer just a springtime ozone hole from 70 degrees south to the South Pole. It is year-round at some level, of the order of 5 percent, and it extends at least to 60 degrees south, and others would say possibly 50 degrees south.

The results we found from Punta Arenas last year conclusively show that chlorine is implicated in the formation of the Antarctic ozone hole, especially about 15 kilometers altitude.

So to turn it another way around, if there is no chlorine in the atmosphere, there would almost certainly be no ozone hole.

So, in summary, just to keep this presentation very short, I think what we can say is, quite simply, there are measurable changes in ozone since 1969 that are either partly or wholly attribute to CFCs. There are differences between what we would have predicted would have happened to ozone since 1969 and what is happening today. That, as Dr. Sherry Rowland says, must cast some level of doubt on our theoretical predictions for the future. The theoretical predictions for the future suggest a few percent change over the next 30 years if the Montreal Protocol were ratified. However, one has to at least ask the question, Why have we underestimated changes in the past? Are we underestimating changes in the future?

As an aside, NASA and NOAA plan to aggressively pursue the uncertainties in our understanding and plan to take some aircraft to Norway next year to get a better understanding of what is happening in the Arctic wintertime.

The weight of evidence strongly indicates that fluorocarbons are primarily responsible for the Antarctic ozone hole.

So I think the big difference between when we first started negotiating the Montreal Protocol and today is that we have now observed changes in ozone, and those observed changes in ozone have partly or wholly been attributed to CFCs.

Thank you.

Senator BAUCUS. Thank you, Dr. Watson.

The final witness is Dr. Sayed El Sayed, of the College of Geosciences, Texas A&M.

Dr. El Sayed.

**STATEMENT OF DR. SAYED Z. EL-SAYED, COLLEGE OF GEO-
SCIENCES, TEXAS A&M UNIVERSITY**

Dr. EL-SAYED. I have been involved in Antarctic work for the past 25 years. My research mostly dealt with the subject of productivity of the Antarctic waters, i.e. the production of organic matter by the phytoplankton. This diagram shows the importance of the krill in the Antarctic food web. The krill feeds primarily on the phytoplankton. And on the krill almost all the other organisms depend for their subsistence, whether you are talking about the whales, the seals, the birds, the fishes, the squids, and even the bottom-living organisms.

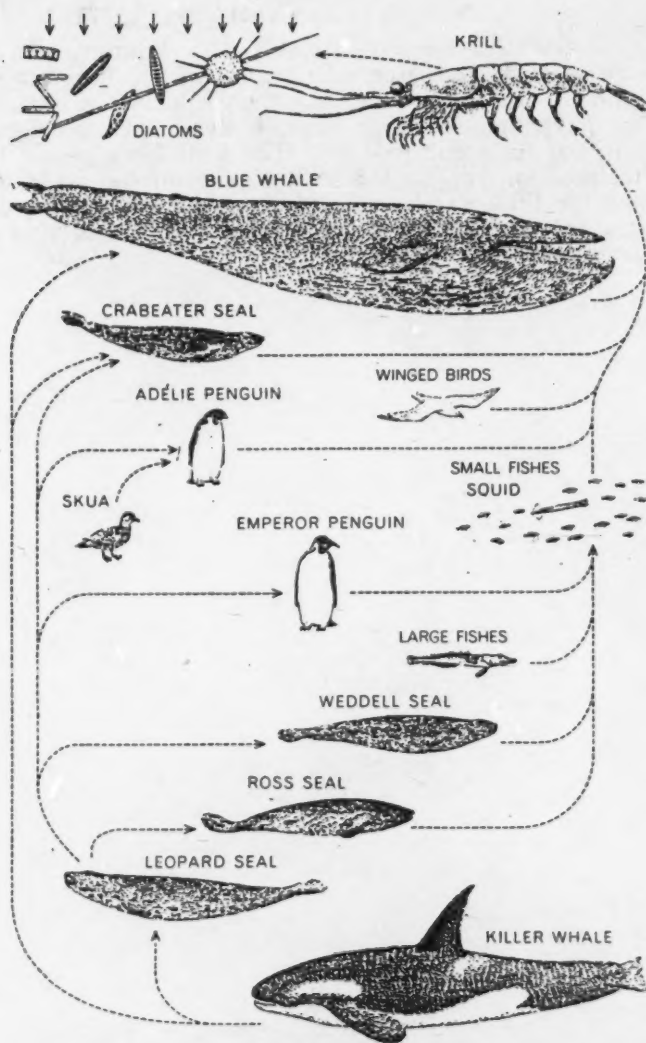


Fig. 1 FOOD CYCLE of the marine animals is based on the krill *Euphausia superba*. This crustacean feeds on diatoms: microscopic marine plants that utilize the energy of the sun (short arrows) to transform nutrients in the water into living tissue. The krill is in turn the food of whales, penguins and other birds, the crab eater seal, squids and fishes. In addition to this basic cycle there is predation by seals, penguins and large fishes on squids and small fishes; leopard seal preys on penguins and other seals and the skua eats penguin eggs and chicks.

Dr. EL-SAYED. If anything would happen to the krill, the whole Antarctic ecosystem probably would collapse. Since the krill feeds on the phytoplankton, we are, therefore, very much concerned about the effects of enhanced ultraviolet radiation on the phytoplankton. This is exactly how I got interested in the subject.

Next slide, please.

This diagram, clearly shows that all the Antarctic organisms, either directly or indirectly are dependent on krill.

Next slide, please.

This is a photo of an adult krill. It looks like a shrimp, it tastes like a shrimp!

Next slide, please.

This is taken from the stomach content of a baleen whale. It has been estimated that a baleen whale can devour between two to three tons a day of krill. This is what you might call a whale of a meal!

Next slide, please.

In recent years a great deal of interest has been shown in the exploitation of Antarctic marine living resources. This is due to the burgeoning world population and the increased demand for animal protein. The Chinese, the Indians, the Soviets and other countries now are focusing their attention on exploiting this huge reservoir of protein supply. And now that the whaling industry has managed to almost decimate the whale population what is left are the fish and krill populations which are now the target of exploitation. It has been estimated that it is feasible to harvest something around 15 million tons of krill annually. Even 10 million tons annually would be a substantial increase, particularly for a protein-hungry world.

Next slide, please.

You are looking at a catch of 35 tons of krill taken by a German trawler in eight minutes! No wonder a lot of people are now very much interested in the marine living resources of the Antarctic, and particularly those of krill.

Next slide, please.

And with the impending exploitation of Antarctic organisms and their potential depletion, those organisms now have to contend with an other kind of depletion, the depletion of the ozone layer over Antarctica.

Next slide, please.

And to add insult to injury, we now have—the “greenhouse effect,” which, if continued to persist, will cause the temperature of the Antarctic Ocean to rise. And since krill is very sensitive to any increase in temperature (in its natural habitat krill is seldom found in waters above 4 degrees Celsius), the “greenhouse effect” with its concomitant temperature increase will have dire consequences regarding the survival of krill.

Next slide, please.

This shows the life cycle in the ocean. I am going to skip that one on account of the time.

Next slide, please.

This shows the importance of the physical process which occurs in the Antarctic, which we call upwelling. As a result of this process the nutrient elements which are essential for the growth of

phytoplankton, are brought close to the surface. It is this process that causes the great abundance of the phytoplankton on which krill and the other organisms of the Antarctic food chain depend for livelihood.

Next slide, please.

The phytoplankton (the grass of the sea) are collected by plankton nets, (mesh-size about 35 micrometers). In recent years researchers discovered the significance of the much smaller-sized organisms, called nanoplankton and picoplankton. On account of their size, they escape through the plankton nets. These organisms are significant in the Antarctic food web because, the small larvae of krill and fish, feed on them. Furthermore, our own research revealed that these organisms make a significant contribution to the biomass and production of Antarctic phytoplankton. And it is the organisms that are very sensitive to any increase in the amount of the UV radiation.

Next slide, please.

This is a photo of an immense phytoplankton bloom. By their being at the surface the phytoplankton probably will be "cooked" by enhanced ultraviolet radiation.

Next slide, please.

This is the type of phytoplankton organisms that live in the pack-ice. The pack-ice is the natural habitat of a special group of microscopic plants (ice-algae). It is on these organisms that krill feeds, especially during the austral winter.

Next slide, please.

This is the site of our research at Palmer Station. The research was funded by the National Science Foundation. However, the views that I am expressing are those of my own.

Next slide, please.

When we arrived at Palmer Station, it turned out to be that the whole of Arthur Harbor was covered with ice. So what we did—next slide—we drew upon our Texas ingenuity and we drilled a hole in the ice and pumped water (containing phytoplankton) to an array of tanks which we used to carry out our experiments. The first tank was under ambient (natural) light conditions. In the second tank we blocked out the UV-A as well as UV-B. In the third tank, we blocked out UV-B only. And in the fourth tank we enhanced the amount of UV by using Westinghouse lamps.

This clearly shows the discoloration of the phytoplankton in the tanks. You will note that when we completely eliminated the UV-A and UV-B (Tank No. 2), the phytoplankton grew very luxuriously. Their photosynthetic rates were higher, by several fold, than those phytoplankton growing in the other three tanks.

Next slide, please.

The photosynthetic activity in the four tanks are shown here.

The amount of radioactivity in terms of counts per minute is 15,000 in Tank No. 2, compared to Tank No. 1 which is about 4,000, and nearly 3,000 when you enhance UV as is the case in Tank No. 4.

Senator BAUCUS. Doctor, could you summarize your dissertation?

Dr. EL-SAYED. Yes, Senator.

Next slide, please.

To summarize, our study showed that under UV-enhanced conditions: (1) contributed to the decrease of the photosynthetic activity of the phytoplankton, quite considerably. (2) Brought about a change in the pigmentation. And, (3) caused a shift in the species composition of the phytoplankton, and particularly the ones that are exceedingly sensitive and vulnerable (these are the nanoplankton and the picoplankton) on which the krill and other small organisms (zooplankton, fish larvae feed).

Senator BAUCUS. Thank you, very much.

I notice that several Senators have joined us since the hearing began. First, Senator Mitchell, who has been long active in this area, too.

Senator, do you have a statement to make at this point?

**OPENING STATEMENT OF HON. GEORGE J. MITCHELL, U.S.
SENATOR FROM THE STATE OF MAINE**

Senator MITCHELL. Thank you, Mr. Chairman.

I do have a statement, but, in the interest of time, I will ask that it be placed in the record and I will take my turn along with the others in questioning of the panel.

Senator BAUCUS. Thank you very much.

[Senator Mitchell's statement follows:]

**OPENING STATEMENT OF HON. GEORGE J. MITCHELL, U.S. SENATOR FROM THE STATE
OF MAINE**

Depletion of the earth's ozone layer is a persistent and troubling global environmental problem. Each round of new data, particularly the most recent report of the NASA Ozone Trends Panel, provides additional evidence that we must make concerted efforts to eliminate our reliance on chlorofluorocarbons, or CFCs.

The data are clear and compelling. The antarctic hole in the ozone layer is no longer the only focus of concern. The Ozone Trends Panel recently announced a finding of a 2.3% to 6.2% decrease from 1969 to 1986 in the annual average of total column ozone during the winter months. These are not the projected calculations. The projected Calculations were an 0.8% to 2.0% decrease. I underscore that the ground-based measurements demonstrate more destruction of the ozone layer than the computer models.

This is an unusual instance in which the rate of environmental deterioration is more rapid than even pessimistic scientists predicted.

Equally disturbing is the additional change to which we are already committed. Chlorofluorocarbons are long lived and CFCs already produced and emitted will continue to cause further degradation of the stratospheric ozone layer, even if we were able to stop all CFC production today. The predicted increase in solar activity may put a brake on additional ozone depletion until 1991, but after that time the Trends Panel anticipates depletion will again increase.

With evidence this clear, the policy choices are limited. We can no longer ask whether we should phase out CFCs.

The question is when to phase out CFCs.

Substitutes are not yet fully developed and tested. They must be developed and tested as soon as possible, while assuring that the substitutes do not pose more of a harm than CFCs. We must also be sure to provide adequate funding for further monitoring of the ozone layer so we can accurately estimate the damage that has been done.

On a global scale, we must again meet with other nations to discuss this data and to press for a phase-out of CFCs. Any other course of action places the globe at too great a risk.

Senator BAUCUS. Senator Symms.

Senator SYMMS. No statement, Mr. Chairman. Thank you very much. I welcome all the witnesses here this morning.

Senator BAUCUS. Thank you.

Dr. Urbach, according to your best professional estimate, could you develop a little more the increased incidence of skin cancer that you think will occur in the next whatever time frame you think most appropriate, given the evidence that is available, and given the uncertainties of predictions, nevertheless, if you could quantify that somewhat, too.

Dr. URBACH. Well, only in very general terms. The only real data on the relationship of ultraviolet radiation to skin cancer is that developed by the National Cancer Institute in two major studies by Scotto Fears and others. It appears that with one percent reduction in ozone there is roughly a 1.7 percent increase in the biologic effective of ultraviolet radiation and twice that much increase in skin cancer for a one percent decrease in ozone there might be $3\frac{1}{2}$ to 4 percent increase in skin cancer.

However, it takes 30 to 40 years of exposure to get enough ultraviolet radiation to the skin to develop skin cancer, leaving aside the genetic background and all the rest of it. Ozone changes are slowly progressive, you know, so it is very difficult to estimate. Clearly any changes require a considerable period of time of exposure to new conditions.

There were some such calculations done in the CIAP days by Dr. Cutchis. At that time, we were concerned that ozone might decrease by 40 or 50 percent.

In two studies that were done a few years ago, six or seven years apart, there was about a two or three percent increase in non-melanoma skin cancer. The problem with ascribing this to ozone changes is that skin cancer is a disease of the old and the population has been aging. As there are more old people, more people have a chance of developing skin cancer, and, of course, people have been exposing themselves more.

I am not trying to avoid your question, Senator. There just aren't any very easy answers. One thing is certain, that given enough time, and the lag time is going to be of the order of 30 years or 40 years, there will be an increase non-melanoma skin cancer.

The problem is a lot more complicated with malignant melanoma, which, of course, is much more serious.

Senator BAUCUS. But you still think that there will be an increase in cancer?

Dr. URBACH. Yes.

Senator BAUCUS. Do you think there will be a significant increase, in your judgment?

Dr. URBACH. Well, with malignant melanoma we wish we knew the exact relationship to ultraviolet radiation, there will be an increase.

Senator BAUCUS. Thank you very much.

Dr. Rowland, I have a question about the models. We're all of us concerned that the models didn't project with as much accuracy as we would have hoped the decline in the stratospheric ozone as well as other consequences. You mentioned something about heterogeneous chemistry, some kind of quantitative analysis in heterogeneous chemistry as maybe the reason why the models are not as accurate as they should be.

What do we have to do to develop, or quantitatively develop a heterogeneous chemistry so that we can develop models that are a little more accurate?

Dr. ROWLAND. I personally don't think that it will be possible to do laboratory experiments that will give you quantitative numbers for use in the models, because the nature of heterogeneous chemistry is that reactions take place on surfaces. If you have an irregular surface, and especially an irregular surface of rather unknown composition, such as one finds in the polar stratospheric clouds over Antarctica, it's very hard to know exactly where the reaction is taking place, how many particles there are, how much each particle contributes.

Senator BAUCUS. Are you, therefore, saying that we will always have this uncertainty? Do we have to go to other analysis to determine, what the public policy should be?

Dr. ROWLAND. I think we will be able to get something about the quantitative effects with experiments in the individual locations. That is, we can try experiments in the Arctic and see whether or not there are relationships between the clouds and the free radicals that cause the ozone depletion. We try experiments in the mid-latitudes in the same way, although we have some trouble getting to the altitudes where the chlorine activity may be occurring.

There are experimental approaches that will give some information. But I am afraid that, in the next few years, we are going to have great uncertainty as to what the future ozone concentrations will be in terms of being able to extrapolate any model with the belief that it will give you good values for what's going to happen 25 or 30 years from now.

Senator BAUCUS. Dr. Watson, I would like your views on what the scientific community can do, or what this Congress can do to help to eliminate or, reduce some of that uncertainty, or do we have to just live with it?

Dr. WATSON. I said, quite articulately, that we need a continued commitment to research within the United States. But specifically, I believe that we can mount a campaign to test, why have the models underestimated the ozone change in the last 17 years. It could be, just as Dr. Rowland has said, that we have underestimated this heterogeneous chemistry. That would mean we have underestimated the impacts of chlorine, which would mean our model calculations would be in error for the future, we would underestimate the impact of ozone in the future. It could be there's been a natural change in meteorology.

However, the first one is a very critical one. Have we underestimated the impacts of chlorine in the future? I think the quick way to test that would be to do the same sort of campaign that NASA, NOAA, and NSF did when we went to Antarctica. We'll have a very vigorous research program. We'll go to Norway. We'll take a certain aircraft and do field experiments to test whether the chlorine in the atmosphere is in a form that can destroy ozone, in the same way that went to Antarctica.

Now, I personally believe that the Antarctic ozone expedition was extremely successful. We got quite definitive results. The Arctic experiment will be somewhat more complex and more difficult to interpret, but I believe the response of the science communi-

ty should be an aggressive campaign to the Arctic as early as next January.

Senator BAUCUS. You're going to Norway, when will that be?

Dr. WATSON. Probably, we would hope to arrive there around January 1st and do a series of experiments between January the 1st and the end of February.

Senator BAUCUS. Thank you.

Senator Chafee.

Senator CHAFEE. I thank you, Mr. Chairman.

I would like to ask Dr. Rowland and Dr. Watson just a yes or no question.

Is there any doubt that CFCs destroy ozone?

Dr. ROWLAND. No, none.

Dr. WATSON. No.

Senator CHAFEE. Is it possible for man in any other way to restore the balance, as it would, or is the only answer just to get rid of the CFCs? Is it—possible to manufacture ozone and, on a massive scale, distribute it in the stratosphere?

Dr. ROWLAND. No. The present circumstance is that 90 percent of the ozone that's in the atmosphere is in the stratosphere. The amount that's produced in Los Angeles smog, for instance, is a very small amount compared to the ozone that's in the stratosphere. The engineering experiment that's going on in the upper stratosphere is that much of the ultraviolet—almost all of the ultraviolet radiation below about 230 nanometers—from the sun is being converted by the atmosphere into ozone. It's an enormous project that the sun's ultraviolet radiation, all of it below certain wavelengths, is producing ozone. In order for man to compete with that would require expending many times as much energy as we are now using for all of the processes that mankind is involved in.

So it is physically inconceivable from that standpoint.

Senator CHAFEE. You discussed the scientific work that you are planning for the Arctic. Is there any other scientific work that remains to be done?

Dr. WATSON. I would argue that there is lots of scientific work to be done. Fluorocarbons and halons are only two of the gases that affect the ozone. I think Senator Bumpers quite clearly pointed out that we really do have to understand the earth system. The climate warming is a very, very serious issue that we are all going to have to grapple with both at the scientific level and at the policy level, and I believe programs such as global change must be funded actively in the next few years.

In addition, I think we do still need to know more about ozone. As Dr. Rowland said, ozone was changing not only in the total column but the vertical distribution. Where is the ozone changing in the earth's atmosphere? That will lead to a change in temperature, possibly a change in circulation, possibly it will also contribute to the greenhouse warming. So there is still much more work to be done to understand how man's activities are affecting our global habitat.

Dr. ROWLAND. May I add to that?

Senator CHAFEE. Yes.

Dr. ROWLAND. My own research group has been measuring methane in the atmosphere for the last 10 years, and finding that it is

going up very steadily, at a rate that's about one percent per year. And this has ramifications because methane is a greenhouse gas; it also tends to reduce the ozone depleting effect of chlorine in the upper stratosphere. Further, we postulate that it may tend to enhance the polar stratospheric clouds and affect the efficiency of chlorine in the Antarctic. And, in addition, it may represent that the earth is just not clearing out pollutants as rapidly as possible.

We know what it comes from qualitatively, it comes from cattle, and from rice, and from swamps, and so on. But understanding atmospheric methane in detail is a project that will take 10 or 20 years. And you should never ask a scientist whether there is anything left to be done.

Senator CHAFEE. I know. We've been through these hearings, as you know, Dr. Rowland, for several years anyway.

Dr. ROWLAND. It's like asking you whether there are any bills that remain to be passed.

Senator CHAFEE. The best defense is a good offense, I guess.

Let me ask Dr. El-Sayed, is there reason to expect that the plankton might adapt into a more tolerant ultraviolet species?

Dr. EL-SAYED. That is a possibility.

Senator CHAFEE. More tolerant of ultraviolet.

Dr. EL-SAYED. That is a possibility, too, but really, we do not know Senator. This is an area that we are very much interested in. Some plants in the tropics and in the subtropical region, have developed some kind of photoprotectant, whereby the plants are able to protect themselves. But we do not know whether such photoprotectants do exist among the marine phytoplankton.

Senator CHAFEE. I see.

Dr. EL-SAYED. And that is what we would very much like to vigorously pursue in the future.

Senator CHAFEE. A final question to Dr. Watson. This is like asking a general if he has enough ammunition.

How did the ozone and greenhouse research fare in the President's budget that is coming up? Not a wish list, but how were you treated?

Dr. WATSON. I think it would be fair to say across the different scientific agencies involved, which are primarily NASA, NOAA, and the National Science Foundation, there seems to be basically a level of effort program, so we did not have any cutbacks, neither did we experience any very significant increases. There were some augmentations, as I understand, to start some things in the next year's budget.

Senator CHAFEE. Did you get inflation, do you know?

Dr. WATSON. Yes, it reflected an inflation, as I understand it.

Senator CHAFEE. All right. Thank you, Mr. Chairman.

Senator BAUCUS. Thank you very much.

Senator STAFFORD.

Senator STAFFORD. Thank you very much, Mr. Chairman.

I would like to address my first question to Dr. Watson also.

Doctor, correct me if I'm wrong, but my recollection is that the treaty of Montreal specifies five CFCs to be reduced over the terms of the treaty, and I think that omits two CFCs that are in production either here or abroad, or both. Is there a danger that some of the countries who have at least signed, but not yet ratified, the

treaty might elect to drop CFCs that they are currently producing and substitute the unnamed additional one or two that might be available to them?

Dr. WATSON. Yes. One particular CFC that is not named in the Montreal Protocol is fluorocarbon 22, and some of the applications of fluorocarbon 22 could replace those of fluorocarbons 11 and 12. On a per-pound basis, the efficiency of fluorocarbon 22 is probably only one-tenth or one-twentieth that of fluorocarbon 11 and 12. Indeed, I believe that is being viewed as a possible substitute.

Another area where one could possibly question the Montreal Protocol is actually methyl chloroform. It is widely used for solvents. It has an ozone depleting potential much less than fluorocarbon 11 and 12, possibly one-tenth, but it is also omitted from the Montreal Protocol, and its production is indeed going up.

Senator STAFFORD. Are there any others that are currently available besides 22, which I had intended to ask about a little later on? It seemed to me there were two others, either one somewhere in the 112, 113, 114, 115 range, and another one around between 11, 12, 13, and 14. Maybe Dr. Rowland?

Dr. ROWLAND. 112 is not covered, and its properties—the basic property that is covered in Appendix 1 of the protocol is that of being a saturated per halo chlorofluorocarbon. That is fluorocarbons 11, 12, 113, 114, and 115. And 112 has that same property and ought to be included simply to forestall the question of switching to one which was technically omitted. I think carbon tetrachloride also, it is not a chlorofluorocarbon, but it is a compound which has an effect similar to that of fluorocarbon 11 and 12. That ought also to be included. In the United States, we don't release very much carbon tetrachloride. We use it mainly for the manufacture of fluorocarbons 11 and 12. But there seems to be a substantial release in Eastern Europe.

Senator STAFFORD. CFC 22, Dr. Watson mentioned. Is that usable as a substitute for the other CFCs, in view of the fact it is only about one-twenty-second as toxic as far as ozone is concerned? Is that an acceptable chemical substitute for the others that are currently being produced?

Dr. ROWLAND. The question of whether it is acceptable in the technical use for each is something that has to be decided by other people who are more familiar with blowing polyurethane foam, or something like that.

As far as the long-term effect on ozone, fluorocarbon 22 is much less hazardous than fluorocarbon 11 or 12. As I have said last week at the National Academy of Sciences, that long-term is really long-term, that is a couple hundred years.

If you take it only over 30 years, then it's more like a factor of 4 or 5 rather than 15 or 20. But 4 or 5 is a big gain.

Senator STAFFORD. Thank you very much.

Dr. Urbach, the industry has cited your study of ultraviolet radiation and cities as a reason to delay further action on ozone depleting chemicals in the past. So my question is, Do you agree that your results are reason to delay any further actions?

Dr. URBACH. Well, that can be answered easily, no. But may I make a brief comment?

Senator STAFFORD. Certainly.

Dr. URBACH. As I pointed out, there are a number of local tropospheric reasons why we didn't see any change in UVB. This is a very short and biologically effective, action spectrum weighted, ultraviolet radiation. That does not mean that there should be any complacency.

But may I add, since Senator Chafee opened the door to the question of research support, if you think there is inadequate support for stratospheric chemistry, there has been no organized support for any studies on the biologic effects of ultraviolet radiation on anything, from phytoplankton to people, since 1975 when the CIAP program ended.

As a biologist, I am always impressed with the fact that while it is clearly terribly important to study what goes on in the stratosphere, the major reason why one wants to know this is because things may happen to biologic systems on the ground. If there were no reason to suspect that, then all that would only be an interesting scientific exercise.

For instance, the financial support for measuring ultraviolet radiation ceased on December 31st. At this moment we expect to fold up the ultraviolet measuring system the day after tomorrow, the first of April. We are waiting for the EPA to let us know whether they can spare the very large sum of \$65,000 for a year's operation. Hopefully they will.

Senator STAFFORD. Thank you very much.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you very much.

Senator MITCHELL.

Senator MITCHELL. Thank you, Mr. Chairman.

You have all suggested the need for more research. I think there is a consensus among the members of the committee, at least, that is necessary. But in this, as in all areas, we must establish priorities because resources are limited.

I would ask each of the four of you to identify now for us the highest priority area of research in your mind. If we were able to provide financial assistance for research in one area, each of you please identify for me which area you recommend.

Dr. Rowland.

Dr. ROWLAND. You didn't give me much time to think about that.

Senator MITCHELL. If you would like to submit a response later in writing, please do so.

Dr. ROWLAND. That might be. A friend of mine who was with the German Umweltbundesamt, their environmental agency, said that they were not going to support any biological research at all because they knew that ultraviolet was bad. And, therefore, if there were ozone change, then they would need to ban the chlorofluorocarbons and they didn't need to do the biology. That is a policy decision that one has to make. It is certainly true that there has been almost no support for biological research. If one wants to take the point of view that we're not sure whether ozone loss and increase of ultraviolet-B would be bad for biology, then you need an enormous research program there.

And so, that's a priority that somebody is going to have to decide. My own feeling is that it's very likely that ultraviolet-B is bad for biology, and that trying to look at all of the biological species is

almost an infinite task. So that I'm not sure that I would put much money into biology, but that's on the assumption that—

Senator MITCHELL. You give us a letter telling us what your answer is.

Dr. Watson, what is your answer?

Dr. WATSON. I think a major effort should go into understanding the fluxes of biogenic gases from different ecosystems, the flux of methane, nitrous oxide, et cetera, and how those gases affect atmospheric chemistry and climate, then how climate back affects the fluxes of the biogenic gases. We have to understand how man's activities affect the ecosystems and how ecosystems affect climate and chemistry.

Senator MITCHELL. Thank you.

Dr. Urbach.

Dr. URBACH. I understand the principle of the Germans and of Dr. Rowland. But there is no doubt in my mind that the problem now is to determine what changes in ultraviolet radiation take place at ground level. There is no question that if ozone changes, something will happen. But there are obviously major effects that appear at ground level, and, therefore, I think that at least the measurement and the definition of the spectrum that reaches earth in many more places than we have now is very important. It is very nice to say that when ozone is reduced there will be more UVB and UVB is bad for people. All this is perfectly true. But this does not tell you how much and what kind of ultraviolet radiation reaches the target, whether it be plankton, or people, or yeast. And I think, to me, at the moment, the primary recommendation would be to continue ground measurements although clearly many studies on biologic effectiveness are important. But you want them ranked in priority.

Senator MITCHELL. That's right.

Dr. URBACH. Let us find out what happens to ultraviolet radiation between 20 kilometers altitude and ground level.

Senator MITCHELL. All right.

Dr. El-Sayed.

Dr. EL-SAYED. Yes, sir. Thank you, Senator Mitchell.

You have to realize that the work that I carried out with some of my graduate students at Palmer Station is the only work of its kind that has been carried out in the Antarctic with regard to the effect of the UV on the marine organisms.

There is another work more or less in the same vein conducted by Dr. Deneb Karentz of the University of California in San Francisco. Her research focused on the effect of the UV on the DNA of the various marine organisms. What I would like to recommend, Senator, is that we need to expand our research effort to include not only the phytoplankton, but other organisms, e.g., the krill, and other organisms as well. They are the ones that we have no idea if they are detrimentally affected by enhanced UV or not. This is very important.

All too often we hear about what is happening to the atmosphere in the Antarctic, however, very little thought has been given as to the impact of the ozone hole on the organisms themselves. This is of great concern to us, marine biologists. As I said in my introduc-

tory remarks, we are dealing now with a population explosion. There are a lot of protein-hungry masses that are counting on krill and on other organisms to augment their diet, and it behooves us to intensify our research effort to study the effects of enhanced UV radiation on the survival of these organisms.

Senator MITCHELL. It's hard to get you guys to give a brief answer. So, my time is almost up. I'm going to ask one other question, and ask you to submit answers to this in writing.

You have described a very serious circumstance, obviously. I thought Dr. Rowland's statement that in order to get circumstances back to where they were in the 1960's, it will take nature three to five hundred years, even assuming a total ban on CFCs. We, of course, hear testimony every day in a wide variety of issues, all of which demand action.

Translating generalized concerns into specific national policy, and furthermore into specific legislative acts, is often very difficult. So my next question to you, which you don't have time to answer orally, if I ask you to submit in writing, is again: What is the highest priority area of legislative activity that you feel we should engage in to deal with this very serious problem?

Attempt, if you can, to reduce your discussion from the abstract, from the scientific, and from the generalized to specific actions which we, as mortal legislators, can do to help deal with the problem. And give us some sense of priority.

Dr. ROWLAND. Put a harsh timetable onto the duPont promise to get the CFCs out of production.

Senator MITCHELL. Well, thank you, Doctor. The length of your responses is improving.

My time is up.

Really, this is a very serious question. I hope you will respond in writing. I, frankly, wish we had a lot more time, but we are limited by time. There are other witnesses, and I am very seriously concerned and anxious to get your written responses on that subject.

Senator BAUCUS. Thank you very much, Senator. That is an excellent suggestion, and I would like to follow it with another request.

I think, unfortunately in this country, too many of us individually worry about ourselves and our own particular areas, we don't work together enough. I think that is more true in this country than any other country in the world.

I would like you to, before you submit those responses to the request of Senator Mitchell, the four of you sit down together and agree among yourselves what the priorities should be.

You can also answer Senator Mitchell's request individually, I urge you to do that, but I also would like you to sit down among yourselves, with a letter signed by the four of you, as to what you agree, the four of you, the priorities should be, the best you can.

Dr. ROWLAND. There are no meteorologists on this panel. Climate change may be the most important.

Senator BAUCUS. You are our panel, you are closer to it than most folks. You know what the problem is. So I would like you, the four of you, to agree what you think the priorities should be. Be-

cause we've got to start working together more, in addition to working separately, individually.

Thank you very much.

Senator Durenburger.

Senator DURENBERGER. Thank you, Mr. Chairman.

I'll begin with Dr. Rowland's new-found expertise in short answers. You've been around since Genesis.

John Chafee, earlier in his exchange with our colleague from Arkansas, brought up the issue of the aerosol ban, and there was some allusion to if the rest of the world let us go it alone for some particular selfish interest.

Do you have an idea as to why the rest of the world failed to ban aerosol spray cans in general?

Dr. ROWLAND. I think the environmental groups in the United States are much more active, much more scientifically knowledgeable, and make their knowledge available generally, so that there is more public information than is typical in England, or France, or Germany. I think a large part of this has to do with the presence of groups like the Natural Resources Defense Council, and the World Resources Institute, and the Environmental Defense Fund that are actively putting out information that presents a different side to what actually is going on.

There was, in addition—Jim Lovelock wrote it out a few years back—that there was a great suspicion in England and in France about the supersonic transports, the whole CIAP program. They thought that was all a policy that was put up here to stop the SST, which was to get at the Concorde. And having thought that we made up the problem to get rid of the Concorde, that we were now making up the problem, continuing the problem. So they've just been suspicious right from the beginning.

Senator DURENBERGER. But the reality is that we made the right decision?

Dr. ROWLAND. Yes.

Senator DURENBERGER. And they should make the same decision?

Dr. ROWLAND. That is certainly true.

Senator DURENBERGER. Doctor, I have a question just a little off the subject, and I hope you can answer it.

Dr. ROWLAND. Sure.

Senator DURENBERGER. We also have been dealing on this committee with the Clean Air Act, and I've been dealing with one part of it, which is toxic air pollutants. And when I saw, just before you got to the genetically engineered penguins on your chart, I saw a famous Minnesota symbol, which is the ice auger, which we use seven months out of the year to fish, and that reminded me to ask you a question about something that I have just begun to hear recently, about the biological activity at the very top or the very surface of lakes, and bays, and ocean. And what I know, little that I know, says that there is a very tiny layer of some kind right at the top that is terribly important.

Dr. EL-SAYED. We call them neuston.

Senator DURENBERGER. Could you talk to us a little bit about that?

Dr. EL-SAYED. Yes. Well, I am familiar with those organisms which we refer to them in our scientific jargon as neuston. They are the tiny organisms that exist only at the very surface, the very top 10 millimeter or maybe a few centimeters of the water column. And these are perhaps the organisms that would be deleteriously affected by any enhancement of the UV, in much the same way that the phytoplankton bloom in the slide I showed earlier.

So this is one of the problems. Another problem is that we do not know what is happening to the organisms below the surface, i.e. in the water column. It is well known that the phytoplankton exist not only at the surface or subsurface, but also to a depth of maybe 100 meters or more. It would be interesting to find out if these "deep" organisms are, too, affected by injurious doses of UV radiation, or if the water column does provide them with a protective shield.

Senator DURENBERGER. Thank you very much.

Senator BAUCUS. Thank you all, very much. We appreciate your help today.

The next panel consists of Dr. Elwood Blanchard, Executive Vice President, CFC Production at Dupont; Marilyn Montgomery, Vice President and General Manager, Genetron, Allied Signal; and David Doniger, Natural Resource Defense Council.

Dr. Blanchard, why don't you lead off?

STATEMENT OF DR. ELWOOD P. BLANCHARD, EXECUTIVE VICE PRESIDENT, CFC PRODUCTION, E.I. DUPONT DE NEMOURS & CO.

Dr. BLANCHARD. Thank you, Mr. Baucus.

I am Elwood Blanchard, Executive Vice President with the Dupont Company. I am appearing before the subcommittee today to provide my company's views on the matters which were raised in your letter of March 24.

Last year we testified that the science did not reflect the need to reduce global CFC emissions, but that we did believe global emission controls were needed. This was then, and it remains today, a global issue.

We strongly supported adoption of the Montreal Protocol, including the scheduled reductions, and believe that our efforts assisted the U.S. in achieving acceptance of this landmark agreement by over 30 countries.

On March 15, the Ozone Trends Panel announced new scientific findings that indicate there has been depletion of global ozone layer, including what has come to be called the Antarctic hole. They also indicated that chlorine from CFCs in some way appears to play a role in these effects.

We understand that there will continue to be substantial uncertainties surrounding the atmospheric science that was interpreted by the experts and released on March 15th. However, we believe that this was carefully conducted review of existing data, and the findings should be seriously considered.

I am not here to debate whether the science is correct and how much certainty we can place on it. I am appearing today to discuss our actions based on these findings.

Dupont reviewed the scientific information as soon as it became available to us, and quickly established as a goal for Dupont the orderly phase-out of production of fully halogenated CFCs. We believe that the replacement of fully halogenated CFCs should be viewed as an opportunity not only for the current CFC manufacturers, but for those with technology and ideas for solutions that are totally different from the ones we have under investigation.

We do not presume to have all the answers to how the world should deal with these new findings. With the changing market parameters attendant with CFC phase-out, heretofore uneconomic technologies may be developed. We have committed to phase out of production. We do not believe that precipitous action is called for, and we propose to conduct our phase-out in an orderly fashion. We pledge to work closely with our customers, and our suppliers, to provide as much lead time as possible during this transition.

Dupont revitalized its earlier program to develop alternatives to the fully halogenated CFCs in 1986, when we concluded that emissions should be controlled. We are continuing this program, but we cannot guarantee that it will be successful. We have identified a small number of chemicals discussed in my written statement, which appear to have the necessary properties to substitute for some important uses for CFCs. However, many uncertainties remain. We still need to develop adequate information that will assure us that they can be made and used safely. We continue to work to develop technology to produce these compounds.

It is not clear to us that we have identified the best route of manufacture or that it will be commercially viable.

In addition, we expect that we will have to invest hundreds of millions of dollars to erect new production facilities, and it is still too early to determine if this investment will even be financially viable.

As indicated earlier, we believe that this issue is global and a solution must be global. We hope that our action stimulates other producers and users to adopt the same goal and work toward an orderly phase-out. We are firmly convinced that the most effective action to address this challenge is the early ratification of the Montreal Protocol by as many of the countries in the world as possible. We also believe that the member States should then be convened as soon thereafter as possible to review the scientific findings and establish appropriate global responses to these new findings.

We encourage you to use your good offices in support of the U.S. efforts to achieve early ratification of the protocol and, following this, to support the prompt review of the science to consider further global limitations.

My written testimony addresses these issues in more detail, and I will be, obviously, happy to answer your questions.

Thank you, sir.

Senator BAUCUS. Thank you very much, Dr. Blanchard.

Marilyn Montgomery, you are next.

**STATEMENT OF MARILYN I. MONTGOMERY, VICE PRESIDENT
AND GENERAL MANAGER, GENETRON PRODUCTS, ALLIED-
SIGNAL, INC.**

Ms. MONTGOMERY. Thank you. My name is Marilyn Montgomery. I am Vice President and General Manager of Allied-Signal's Genetron business unit. We appreciate the opportunity to share our views with this committee. And, as you have requested, we have attached production statistics to our written testimony.

The reports of NASA's Ozone Trends Analysis are new and disturbing information to CFC producers, to users, to consumers, and to all of us as citizens concerned about the environment.

Allied-Signal has not yet been provided with this new data for our own review. We expect to receive it shortly and we will examine it as rapidly as possible. We would like to thank Dupont for providing us with their interpretation of the data. It should help us expedite our own analysis.

But even without the data, one message comes through clearly, this problem is a global one.

To be effective, any solution must be international in scope. Fortunately, the elements of a realistic and effective solution are already in place in the form of the Montreal Protocol.

The protocol recognizes ozone depletion is an international problem that can only be solved by worldwide action. Allied-Signal endorses this approach completely, and urges all nations who have not yet ratified the protocol to do so quickly. International ratification itself will provide the incentives necessary to commercialize the new products now under development.

The ultimate solution of this problem will be the development of safe, non-ozone-depleting substitutes. We have intensified R&D programs to meet this challenge.

Reflecting this commitment, Allied-Signal announced yesterday an agreement with Atochem, a wholly-owned subsidiary of France's Elf Aquitaine group. We will develop jointly a full family of non-ozone-depleting substitutes for CFCs, including 134A, 123, and 141B. This agreement encompasses research to develop process technology and pilot plant construction leading to full-scale commercialization and, hopefully, for a rapid introduction of new products.

The companies have already made quantities of HCFC-123 available to end-users for testing and evaluation. By the end of June, sufficient amounts of HCFC-141B will be available for end-use testing. And during the fourth quarter of this year, similar quantities of HCFC-134A will be on hand.

Under normal circumstances, the development of a new product from the inception of process research to the initiation of commercialization requires 7 to 10 years. There are three distinct sets of activities which occur during this time period.

The first, laboratory process research. During this initial phase of activity, alternate chemical routes to the new product are first identified and then compared by synthesizing them on a small scale. During this phase, consideration is given to minimizing the number of steps necessary to produce the new product, maximizing

the yield and reducing the number of by-products formed. This phase can usually take two to three years.

Then the pilot plant. During this phase, the selected process is practiced on a larger scale. Product purity and by-product handling and disposal are key objectives. This phase could last two to two-and-a-half years.

And third, commercialization. Construction of a commercial facility generally begins only after the pilot plant operation is successfully demonstrated, and only when chronic toxicity studies are near completion. An elapsed time of two-and-a-half to three years is not unusual.

Our projected schedule telescopes all of the steps. Pilot plant construction parallels lab work. Full plant design and construction will begin before the process has been completely demonstrated and considerably before chronic inhalation test work is completed. This enhances the technical and financial risk considerably from the normal timetable, and most likely will impose a manufacturing cost penalty, at least in the early years of production.

Substitutes for CFC-113, on the other hand, are in a much earlier stage of development. We have an active program to identify non-ozone-depleting solvents. We are already offering blends of CFC-113 which reduce the amount of fluorocarbons used in cleaning baths for printed circuit boards. We are designing new equipment capable of handling the boiling points of potential solvent substitutes. We plan market introductions in the near future.

As producers, we know that we are doing as much as we can at this point to reach a workable solution as rapidly as possible. We know that non-ozone-depleting substitutes will be the solution. We believe that the international approach taken by the Montreal Protocol is the correct one.

The new scientific data on global ozone depletion is significant. It can provide an added impetus to other nations to join in the protocol quickly. To get this done, we urge that the United States call for an immediate review of this new data by scientists who worked on the development of the protocol. The review provisions of the protocol can and should be expedited.

Almost everything is now in place to solve this problem in a practical and timely way. Formal adoption of the protocol by the world community is the next big challenge. It's a very important challenge, and is one that all of us must work to achieve if we are to have any real solution at all.

Senator BAUCUS. Thank you very much, Ms. Montgomery.
Mr. Doniger.

STATEMENT OF DAVID D. DONIGER, SENIOR ATTORNEY, NATURAL RESOURCES DEFENSE COUNCIL

Mr. DONIGER. Thank you, Senator.

Two years, in a conference sponsored by EPA and UNEP leading up to the first negotiations, I first proposed a 10-year phase-out of CFCs. That notion was regarded somewhat as a radical notion back then. It is now obvious that a phase-out is mainstream thinking.

But it is obviously just a proposal, not an accomplishment. Some time in 1943, General Eisenhower must have sensed that he was

going to win the war, but he knew there were many steps to be taken before the victory was real. That is where we all stand on ozone depletion now. We have to bring the phase-out to reality.

I think it is clear that we're facing a global emergency. We're already past the point of ozone depletion that EPA predicted would occur under the Montreal agreement and its own regulations by the year 2050, 60 years from now.

So what shall we do next? I would like to talk about six specific areas where concrete steps can be taken in the coming months to move us towards a CFC and halon phase-out.

First, the CFC and halon industry, producers and users alike, here and abroad, must be pressed to take the phase-out pledge. The pledge should contain specific deadlines for action, which are absent from the Dupont pledge. Specific measures should be taken by users, as well as producers, to make early reductions.

Second, the industry, environmentalists, and the Government, have a great deal of leverage to exercise to get early ratification and a commitment to immediate reassessment of the protocol. On that point, I would like to amplify a suggestion Senator Baucus made with regard to the seven-nation summit in June. I suggest that Secretary Shultz make it clear to each of the allies represented at the summit that the President expects ratification to have occurred by those countries by that time, and that he expects them also to have announced support for an immediate reassessment of the protocol. These are our allies. They have signed the agreement, they have taken credit for it. Now is the time to make them perform on it.

Third, the U.S. should call for and UNEP should schedule an immediate diplomatic reassessment of the Montreal protocol. The largest part of the science review really has already been done. The NASA-coordinated review was cosponsored by UNEP; it was an international review. The conclusions are there. It is time to bring the diplomats together as soon as possible, certainly in January or February, right after the treaty is to take effect, if not before then.

Fourth, turning domestically, the EPA must be pressed to carry out its obligations under the existing Clean Air Act, which are not satisfied by a 10-year half-way measure. The existing Clean Air Act requires EPA to control domestic CFC and halon production and use sufficiently to meet the environmental needs, and environmental needs are not satisfied by a 50 percent phase-out.

We have, as I have testified in the past, urged EPA to institute a complete domestic phase-out in the regulations that are going to be promulgated this August pursuant to the court-ordered deadline resulting from NRDC's lawsuit. There should be trade provisions and a windfall profits fee in those regulations. There is a \$2 to \$6 billion windfall, according to EPA, that may be reaped by the very companies which have brought us the damage to the ozone layer. It is unthinkable that these companies should profit by a windfall from the phase-down.

Finally, Congress should not leave protection of the ozone layer to the Executive Branch. In addition to holding hearings, the Congress can help in several specific ways, some of which you have already touched on. The first is to ask each U.S. producer and user of CFCs and halons to make a specific phase-out pledge. Second, press

the Secretary of State and the President to make ratification and a commitment to reassessment a reality by the June economic summit. Third, demand that EPA carry out a phase-out and implement a windfall profits fee within the Clean Air Act regulations due on August 1st.

But the most important thing, I think, is that you should move S. 570 and S. 571 into law now. You should not leave the job to the EPA, in this administration or any other.

The picture is clear enough for Congress to act, itself, to phase out CFC and halon usage over six to eight years, as these bills would do, establish an appropriate windfall production fee, and implement the necessary trade provisions to make sure that no other country takes a free ride on the benefits of our action.

Look at where we are. We are committed to 100 years or more of ozone depletion, to millions of cases of skin cancer and other disease, to untold damage to the environment and the climate. We have waited 15 years too long to end the use of these chemicals. Yet it will be even worse if we don't act now. There is the basis, I think, for the first time, for a broad consensus among government, environmentalists, and industry on a rapid complete phase-out. If we take the steps I have outlined above, and the other ones you've mentioned today, I think we can achieve a new worldwide agreement in as little as a year, and to end the use of these chemicals by the end of the century.

Thank you.

Senator BAUCUS. Thank you very much, Mr. Doniger.

I would like to ask Dr. Blanchard and Ms. Montgomery: Do you agree with everything Mr. Doniger said, with the possible exception of the windfall profits tax? The specific course of action that he recommends for this country.

Dr. BLANCHARD. The courses of action, I would like to read them as opposed to just hear them, and study them a little bit, Senator. But fundamentally, other than the fees and tax provisions that he speaks of, I think many of the actions are very consistent with what we have heard from both you and the other panelist.

Ms. MONTGOMERY. From our perspective, and also I would like to see it more clearly, we would want to focus more on an international solution than have us here in the United States move unilaterally and put ourselves in a less competitive position, and in so doing, take the pressure off the rest of the world to ratify the protocol.

Senator BAUCUS. That is basically, I think, the thrust of Mr. Doniger's suggestion, that is, it is a global, international problem.

Based upon your experience in selling products in this country, but more particularly overseas, what's your assessment of how successful you and we, together, will be in encouraging other companies to phase out the production of CFCs, other companies?

Dr. BLANCHARD. I don't know that we will be very successful in encouraging other companies to take actions unilaterally. I think we can be successful in supporting, through governments, regulations leading from a revised UNEP protocol that will lead to that. But I wouldn't look for voluntary actions. I think that it is going to require ratification of the UNEP protocol, modification to a complete phase-out, establishment of timetables and international ac-

cords, and we've got plenty of leverage if we elect to use our trade capability to leverage that.

Senator BAUCUS. So you suggest exploring those avenues as well?

Dr. BLANCHARD. Yes.

Senator BAUCUS. That is, trade sanctions.

Ms. Montgomery, does Allied-Signal agree that these various gases listed in the protocol should be phased out?

Ms. MONTGOMERY. Excuse me?

Senator BAUCUS. Does Allied-Signal agree with Dupont that these gases mentioned in the—

Ms. MONTGOMERY. Allied-Signal has not had an opportunity to review the data that came out of the Ozone Trends Panel. We are trying to get it. We will be reviewing it as rapidly as we can. I could speculate that if we confirm and agree with the data, that we would have a change in position. More importantly, what we have examined is our action. We are doing everything we can to develop substitutes, and nothing can change according to any type of scientific data at this point.

Senator BAUCUS. I can only speak for myself, but I urge Allied-Signal to expeditiously as possible follow the lead of Dupont in phasing out.

I would like to ask both of you, too, your reaction to Mr. Doniger's suggestion as to development of substitutes. The very industry that has produced the chemicals that are causing the problem is going to be the industry that is going to reap windfall profits with development of high-priced substitutes.

Dr. BLANCHARD. Well, I can assure you, Senator, I am not going to hold my breath for windfall profits from the chlorofluorocarbons business. Since the early 1970's, I can only describe our performance in an economic sense as abysmal. It's been a cash trap for the company. And, as a result, the theory that this phase-out is going to axiomatically result in excess profits flowing to chlorofluorocarbon manufacturers, I don't think is well founded. For example, in the year 1987, when we were advocating support of the phase-down proposal, the competitive factors in the marketplace for chlorofluorocarbons resulted in an 8 percent decline on a year-to-year basis in prices, as far as the Dupont Company is concerned. That does not lead to windfall profits.

I believe that this is probably not an issue, and that, if it becomes an issue, it should be dealt with at that time, and I think that there are mechanisms that you can use through taxing agencies and others to identify it (windfall profits) if that should it become an issue.

Right now we need incentive in the form of a continuing profitability and a generation of some earnings to pay for the horrendous research expenditures that we are putting into the development of alternates. We are spending in Dupont roundly \$10 million a year, and the current business would not support that kind of expenditure if we did not have some prognosis for developing alternates that could generate an earnings potential to cover those investments.

Senator BAUCUS. I commend you for what you have done thus far. I think it is a major development and a very healthy, salutary development when a major producer, on its own, announces it is

going to phase out production of chlorofluorocarbons. I commend Dupont for that action. And I also commend Allied-Signal for the action you've taken thus far, but strongly urge Allied-Signal to go even further in publicly committing to a phased-out reduction.

There are many other problems and there will be other problems as we work this out and go down the road, and we'll cross some of those bridges when we come to them. But at this point, I want to thank you for what you've done. I appreciate it.

Senator Stafford.

Senator STAFFORD. Thank you very much, Mr. Chairman.

Dr. Blanchard, I want to compliment Dupont also on the position you've taken, and hope that Allied and the others will follow your example worldwide.

Your detailed statement interested me a good deal because I've been thinking about the potential candidates to replace the CFCs that you intend to drop on an orderly basis as fast as you can have an adequate substitute. And I notice that CFC 22, on page 3 of your statement, is indicated to be presently under manufacture and widely used for refrigeration.

Does that include automobile and household air conditioning as well as storewide distribution?

Dr. BLANCHARD. It includes fixed household air conditioning and heat pumps. It does not include mobile air conditioning, such as automotive or refrigeration.

Senator STAFFORD. Could it be used for those purposes?

Dr. BLANCHARD. No, not without significant modifications to that equipment. And I might add, Senator, that one of the issues that I see that are going to add to the complexity of our path forward are the fact that none of the alternates that we've identified are drop-in replacements for Freon 11, 12, and 113. They will require some modification of the equipment, and we think quite substantial. It is going to exacerbate the ability to move forward on it.

Senator STAFFORD. Certainly I want to have a realistic understanding of what the problem is.

I note in your statement that you identify 13 potential candidates for replacement, but that several of those have been disqualified because of toxicity tests that they failed, that you have still 123, 134A, 141B, and 22 that—22 is in use and the others are undergoing toxicity tests.

How much longer could you suggest the toxicity tests might take?

Dr. BLANCHARD. Toxicity tests, I believe, are two-year tests. Is that right, Joe?

Dr. GLAS. There is a continuum of toxicity tests—

Senator STAFFORD. Would you please identify yourself?

Dr. BLANCHARD. This is Dr. Joseph Glas, Director of the Freon Products Division.

Dr. GLAS. The toxicity program is a continuum, beginning with initial screening tests through, ultimately, a two-year animal inhalation test. And a consortium of 14 companies now has been formed to accelerate the pace of those developments. Programs have been laid out for 123 and 134A. The initial screening work has now been contracted to laboratories. We expect that the two-year inhalation

tests would begin some time next year. It takes two years to do a two-year test, another year or two to do the detailed pathology.

Senator STAFFORD. Thank you.

Mr. DONIGER. May I comment on that?

First of all, the new consortium to do testing is an interesting way to do it institutionally. It would be better if the EPA and other appropriate public authorities were allowed into the design, conduct, and review of the studies along with the industries, and I understand there have been some problems in that regard.

And the second thing is that although you can't make the animals live any faster than two years, there is some flexibility about how quickly you start these tests and how quickly you take the animals apart at the end of the test and find out what's happened and report the results. And there should be no lag in getting this work done.

Senator STAFFORD. All right, thank you.

Coming back to you, Dr. Blanchard, I am sure, at least as a layman I hear these rumors and see some stories that there is acute competition abroad, possibly in Japan and some of the industrialized countries of Europe, to beat Dupont in finding salable usable substitutes.

Could you comment on what the state of competition might be from your perspective?

Dr. BLANCHARD. From my perspective, I think that we are reasonably well positioned competitively. The picture changes every day. I learned last evening, when I arrived in Washington, of the Allied-Signal agreement with the French concern. So I can't tell you what the status is. This is a competitive environment and we're subject to all the usual antitrust arrangements. In fact, we went to some considerable effort to be able to do this toxicity testing as a panel of companies, to avoid the implications there.

I don't know of anybody being significantly ahead of us. If they are, they are being very quiet about it.

Senator STAFFORD. Obviously there is international competition to try to come up with substitutes.

Dr. BLANCHARD. Yes.

Senator STAFFORD. Thank you very much.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator Stafford.

Senator Chafee.

Senator CHAFEE. Thank you, Mr. Chairman.

I would like to ask both Ms. Montgomery and Dr. Blanchard on the antitrust problems that you run into. Obviously, we are here to do everything we can to help you folks move ahead in this area.

What do you do when the antitrust situation—when any time you get 14 companies cooperating, you've got those concerns—what did you do? Do you ask the Justice Department for clearance, or how did you do it? And is there anything we might do? Do you have any suggestions to us as Senators where we might be helpful to you?

Dr. Blanchard, why don't you go first.

Dr. BLANCHARD. Yes. Senator Chafee, what we did was to make it very public that we were interested in developing a consortium of participating companies to conduct this toxicity testing and made it

available to all producers, so that there couldn't be an accusation of exclusion on the part of one producer and that they were, therefore, disadvantaged. And with that, and then obviously the careful selection of the persons that you involve in such a group to ensure that it is only the technical persons and not commercial persons that might lead into areas that would be inappropriate, those are the two fundamentals.

Senator CHAFEE. Do you have anything that you'd like us to do if we could do it? Not saying we can, but if we could, would you have us do anything to help you in relieving you of your concerns?

Dr. BLANCHARD. In the antitrust area today, Senator, I can't give you a specific. As we start to phase out, we are going to deal with certain contractual and customer obligations, and there's going to be tremendous difficulties, in my estimation. I think we are just touching the tip of the iceberg, and how this can occur in products that are used so widely and through such complicated distribution systems to ensure that we don't end up with groups feeling they have been disadvantaged and the associated problems with that.

Senator CHAFEE. All right. Mr. Doniger.

Mr. DONIGER. The problem that Dr. Blanchard is referring to is that when the supply contracts, it's like creating an OPEC for CFCs. The supply contracts, the price is going to go up. It has to go up to make alternatives competitive. But the money shouldn't go into the producers' coffers as a windfall. That's why we need a windfall profits fee or tax.

Senator CHAFEE. Well, okay.

Dr. BLANCHARD. OPEC is an excellent example.

Senator CHAFEE. Let's not get into a debate on that. We'll leave OPEC out of this for awhile.

Let me ask you this. The suggestion is that CFCs are essential in the production of some items. Well, of course, the definition of "essential" is an illusive one. I suppose nothing—we could live in a cave and run around with all we need is food and water to survive. But what are some of the things? I don't consider a styrofoam cup very essential. What do you define as essential?

Dr. BLANCHARD. That's risky to get into, deciding what are—

Senator CHAFEE. How much of your production would you believe to be essential?

Dr. BLANCHARD. I consider refrigeration to be a very essential item in protecting food.

Senator CHAFEE. How about automobile air conditioners?

Dr. BLANCHARD. In Houston they are more essential than perhaps in the northern climes.

Senator CHAFEE. It's against the puritan spirit.

Dr. BLANCHARD. I understand that, sir. On the other hand, there's a huge portion of the Southwest, and particularly where there are no windows that open in the buildings, there's no way to manage air movement, and so forth.

Senator CHAFEE. All right. Of your total production, how much would you think was essential? I think cleaning fluid for ships, I would put that in the essential category.

How much goes for McDonald wrappers?

All right, Ms. Montgomery, why don't you give that?

Ms. MONTGOMERY. I would guess, and I could provide you better numbers at a later date, that probably 60 to 70 percent I would consider to be of rather notable societal benefit, and then we move into gray areas where I'm really not in a position to be able to say which is more important.

Dr. BLANCHARD. All right. Sixty percent would include refrigeration and 113 which is used in computer applications.

Senator CHAFEE. All right. What do you say, Mr. Doniger?

Mr. DONIGER. Well, these are very important uses, but there also are fast ways to economize on their use. The recycling of auto air conditioning fluids could get a lot more cooling out of the same amount of fluid. You just don't have to throw it away into the air.

Senator CHAFEE. I take it now there's no incentive for recycling of the automobile CFCs, is that right?

Dr. BLANCHARD. There is no mechanism in place to do the collection in particular. We are looking at that with various associations to see if there's a way of doing that. In the case of the 113, which is used in the computer industry, we're promoting efforts to try to increase recovery and reuse.

Senator CHAFEE. Thank you.

Thank you, Mr. Chairman.

Senator BAUCUS. Senator Durenberger.

Senator DURENBERGER. Mr. Chairman, I am just going to take a minute to describe a series of questions I want to ask all of these panelists.

I see that, for this panel in particular, that the three questions we have to answer are what is an orderly transition or what's an orderly phase-out? Should the U.S. go it alone? If it is forced to, what does it do, how can it make sure it doesn't go alone? And the third one is the question that's been touched on a little bit, which is the issue of the marketplace and the potential windfall.

And I would like to explore the phase-out issue with a series of questions that will deal with the market, particularly as the two of you from Dupont and Allied-Signal see the market in the world. I would like to explore the so-called windfall issue with what might turn out to be kind of an elaborate series of questions, but I think sort of important to the issue, because there are certain presumptions which, Mr. Blanchard, we take your statement as the reality at Dupont, but when you see almost \$3 billion a year in CFC sales, you've got half of it—

Dr. BLANCHARD. No, sir.

Senator DURENBERGER. No?

Dr. BLANCHARD. Six hundred million dollars a year.

Senator DURENBERGER. Six hundred million? Okay.

The problem is, how does this phase-out, and then the demand in the marketplace that John Chafee was just getting at, relate to each other, and what might that do to price?

I would guess folks who are sort of experts, have been in this field for a long time, might best answer those questions for us. So, if you don't mind a series of those questions, Mr. Chairman, and this panel, I will put those together and submit those.

Dr. BLANCHARD. In writing?

Senator DURENBERGER. Yes.

Dr. BLANCHARD. That would be very helpful to us. We would be delighted to respond, sir.

Senator DURENBERGER. Good. Thank you very much.

Senator BAUCUS. I thank you all very much.

We have a vote now, so I will have to conclude this hearing.

On behalf of the rest of the committee, I thank the witnesses who have come before us today. And also again, to commend Dupont and, hopefully, Allied-Signal for actions they are taking.

We will continue to address this question in the next remaining months of this year, including requesting EPA, the actions they are going to take in view of the Trends Report. In addition, S. 570 and S. 571 are bills which this committee will address very seriously to see what appropriate action concerning those bills should be, the report result being to encourage other countries to ratify the protocol and to reopen the protocol as quickly as possible.

Thank you. The hearing is adjourned.

[Whereupon, at 12:18 p.m., the subcommittees were adjourned.]

[Statements submitted for the record follow:]

Senator Dale Bumpers
Subcommittee on Hazardous Wastes and Toxic Substances
March 30, 1988

Fifteen years ago this Fall, Professor Sherwood Rowland and his research student, Mario Molina, put forward their dramatic proposal that chlorofluorocarbons were depleting the protective stratospheric ozone layer. And two years later, an interagency task force on the Inadvertent Modification of the Stratosphere (IMOS) published a major report on what was known about depletion and its adverse effects for human health, agriculture and natural ecosystems. Then in September of 1975, Senator Domenici and I held hearings on all aspects of this issue, and after listening to atmospheric and other scientists, industry representatives and government agency representatives during nine hearings, I became convinced that we were dealing with a problem that had the potential for major adverse consequences, not just for the United States, but for the entire world.

Almost 12 years later now, we have reports on the Antarctic ozone hole, and the Ozone Trends Panel has revealed how right we were then, and how belatedly we are reacting now.

Let me recount briefly some of the history of the ozone depletion issue because I believe it provides us with important lessons about how we should respond to this immediate problem and to the even more serious greenhouse issue which we are being warned about by many of these same researchers. If we wait 12 years to deal with this problem, the delay may be much more devastating than the ozone depletion.

But back to the chronology. By the mid-1970s, atmospheric scientists such as Rowland, Cicerone, McElroy, Anderson and others had compiled impressive data suggesting, but not proving, the CFC-ozone depletion link. Their relatively simple models predicted ozone depletion levels in the 5 - 10% range if we continued to release CFCs at then current rates. There were uncertainties in the models, gaps in our knowledge of stratospheric chemistry and a shortage of actual measurements of stratospheric chemical species. It was clear that it would be nice to improve our scientific understanding, but it was also clear that waiting to gather the information needed to convince

everyone was courting disaster. CFC production was doubling every decade and that's just about the minimum time for CFCs to diffuse up to the stratosphere where they destroy ozone. So we did what all good politicians do: we waited until we saw a detectable decrease in ozone. At that time it was felt that the smallest detectable loss was 5%, which meant we were faced with twice that amount from chemicals already in the atmosphere if we stopped releasing CFCs immediately. Even a 5% decrease was, in my judgment, unacceptable.

Unable to respond fully to the problem because of strong industry opposition, the Congress in 1976 passed the usual political compromise. We increased funding for research which we promptly reduced again in the 1980s just when it was needed most. Those cut-backs cost us a great deal of time, during which millions of tons of extra CFCs were released into the atmosphere.

Secondly, we knew that 62% of CFCs were used in aerosol sprays, so we passed amendments to the Clean Air Act that phased out those uses. Despite Senator Packwood's and my best efforts,

only 28 Senators voted in favor of our 1976 amendment to halt the use of CFCs in aerosols by January 1, 1978. Instead, we had to wait for the bureaucratic process, and fortunately the FDA Commissioner, Dr. Alexander M. Schmidt, ruled that the risks were just too great for us to continue using CFCs in aerosols. It was too dangerous to wait for definitive proof.

Most of us thought we had bought a little insurance and a little time to develop substitutes by banning the non-essential uses of CFCs in aerosols. Unfortunately, only Canada and a few Scandinavian countries followed suit and joined our ban on aerosols. By 1980, DuPont announced that it was no longer pursuing alternatives to CFCs despite its assurances in the 1970s that it was using this time to develop substitutes. And what about the science? Although we put up a couple of satellite experiments, we generally allowed research funding to decline until the next crisis erupted in 1985 with the dramatic discovery of the Antarctic ozone hole. My worst fears were confirmed.

So here we are today faced with the disappearance of over half the column of ozone over Antarctica each October, a condition which lasts longer each year. These massive losses and their sudden onset at the end of the 70s make a mockery of our debates in 1976 as to whether there would be a 3% or a 7% decrease in ozone from CFCs. The impressive correlation between ozone depletion and the presence of chlorine in the stratosphere that was documented by Professor Anderson last Fall leaves no doubt as to the role played by CFCs. You will hear more about the scientific basis of these findings from Professor Rowland, plus a dissertation on the likely devastating effects on the food chain of the southern oceans from Professor El-Sayed.

The Antarctic ozone hole is a dramatic event for which there is no known remedy, and which will require more than a century to heal even if we were to stop releases now. Of even greater concern for us is the evidence of global decreases in ozone that affect human populations directly. What is troubling about the decreases reported by the NASA coordinated Ozone Trends

Panel is that they exceed predictions by substantial margins. Dr. Watson will fill us in on the grim details later this morning, but I would like to suggest that these data only confirm the direction we knew we were headed 12 years ago. The tragedy is that despite the fine work done by Senator Baucus and the members of this subcommittee, despite the careful negotiations at Montreal, and the successful ratification of the protocol last week, and despite DuPont's dramatic and laudable announcement to phase out the production of CFCs, we are now where we should have been a decade ago. Had we acted then rather than reacting now, we would be completing the transition to new technology today rather than just beginning it.

While we cannot undo the damage already suffered by the upper atmosphere, or prevent the additional harm that is yet to come to human health, agriculture and the natural world, there are some actions that we can and must take. Although the action we took had a dramatic effect in reducing worldwide aerosol use from 62% of the CFCs to 37% today, other uses were expanded and

we are now back at historically high production levels. The Montreal Protocol would reduce production to half the 1986 levels by 1999, but because of the drawn out implementation time, chlorine levels will increase to twice their already unacceptable levels.

Mr. Chairman, we must deal with this problem rapidly and effectly. I don't have a comprehensive proposal, but I suggest that the following action be taken immediately:

- (1) To date, only Mexico and the United States have ratified the Montreal Protocol to limit CFCs. As weak as this protocol is, it is an important first step. The Senate should press its parliamentary colleagues in Europe, Japan and the USSR to move quickly to ratify the treaty. Then they should urge Mr. Tolba, the director of UNEP, to reconvene the parties within six months from now to reconsider a more rapid phase-out. A letter signed by 100 Senators would help move other nations forward, and I hope the Chairman will join me in circulating such a letter before we leave here Friday. The upcoming economic seven nation economic summit will also be an

ideal forum in which the President could press our economic partners and allies to move on this issue.

- (2) To implement the Montreal Protocol, EPA is proposing a system of free rights to CFC producers on a percentage basis of their 1986 market share. This policy will slow the introduction of alternatives. A high fee of five to ten times the current price of \$0.50 to \$1.00 per pound would not only encourage alternatives but would promote conservation and reuse of CFCs during the transition period. A bill that would accomplish this goal has been introduced in the House and similar bills are before this committee for the Senate. We should hammer out the differences and act on these bills immediately.
- (3) We should impose a near-term ban on non-essential uses of CFCs, and the use of CFCs on non-essential things such as styrofoam food packaging and cups, open foam blowing and the flushing of auto and home air conditioners should be discontinued very quickly.
- (4) We must fund our share of international programs such as those of the World Meteorological Organization, the United Nations Environment Programme (under whose auspices the Montreal

Protocol was negotiated) and the International Geosphere, Biosphere Programme (IGBP). We have not funded these programs fully in the past, but we must meet our international obligations in the future to solve this global problem.

- (5) Finally, we would not even be aware of this problem had not scientists like Professor Rowland and others persevered even when the federal agencies and the Congress short-changed them in terms of research funds. I personally wish to thank Professor Rowland for his work and for his patience. I know that he was often subjected to unwarranted criticism and personal attacks.

We cannot expect scientists like him to be around when we need them unless we are willing to support not only research, but the training and support of the next generation of scientists in what is coming to be known as earth system science.

I recognize that there are budget constraints, but we must reallocate our priorities to raise the Mission of saving Planet Earth above the Manned Mission to Mars, the hypersonic airplane

or the supercollider. We must examine programs at NASA, NOAA, NSF, DOE, EPA and other agencies to be certain that these global problems are being adequately addressed. I plan to do all I can to shift research priorities to the study of global change issues when we carry out the appropriations process this year, and I urge the support of the members of this committee.

Finally, I can only hope that we have learned a valuable lesson from all this. If we have not, we are facing an even more ominous threat -- the threat of global climate change arising from the greenhouse effect. Once again, scientists are in agreement that the effect is real and that the consequences of altered weather patterns and rising sea level will exceed anything the earth has seen in the last 100,000 years. If timid politicians again refuse to face this dramatic problem head-on, we will pay a staggering price, and stand fairly accused of gross negligence by future generations. If we commit ourselves to say a 30-year project to study this issue and monitor the results, we may reverse the problem. A Global Change 2020 Program could also

alert us to other issues that have not yet even occurred to us. We must begin now to change those activities that involve both the greenhouse effect and a host of other interrelated issues.

We can also begin to act now to reduce the more serious consequences of the greenhouse effect. While carbon dioxide from burning fossil fuels is responsible for half of global warming, CFCs contribute 15 to 20% of the projected global warming. The problems of ozone depletion and global warming are interrelated. Will the proposed CFC substitutes designed to reduce ozone depletion increase or decrease the greenhouse effect? Improving energy efficiency as this Congress did last year with appliances will slow greenhouse warming, improve our energy security and economic competitiveness, and reduce acid rain. Developing renewable energy resources will accomplish these same goals. Promoting reforestation will not only reduce the build-up of carbon dioxide, it will prevent erosion and loss of biological diversity as well as provide renewable resources.

In both ozone depletion and the greenhouse effect, we clearly face problems of global dimension that will affect all nations on a scale that has never been encountered in human history. The encouraging fact is that there is something that we can do . It is also clear, however, that we must begin acting now to slow the growth in the emission of greenhouse gases. Let us not repeat the mistake of not acting in time to slow ozone depletion. Waiting until a clear greenhouse fingerprint is unequivocally proven will, if current models are correct, commit us to substantial additional warming. These same studies also show, however, that by taking action of the kind described here, we can reduce future warming significantly. By a prudent choice of policies that simultaneously slow the release of greenhouse gases and help solve other problems, we can effectively and prudently buy ourselves some insurance against a rapid global warming and its destructive consequences. It is both an exciting opportunity and a challenge for Congress to determine the policies that will determine our future.

Testimony of F. Sherwood Rowland, Professor of Chemistry,
University of California, Irvine, March 30, 1988
Senate Committee on Environment and Public Works
Subcommittee on Hazardous Wastes and Toxic Substances

Three important geographical regions of stratospheric ozone depletion have been thoroughly investigated during the past sixteen months by the Ozone Trends Panel of the National Aeronautics and Space Administration. The first of these is the question of loss of ozone centered near 40 km altitude over temperate and tropical zones, the anticipated altitude of maximum effect of the "standard" ClO_x chain reactions first identified in 1973. The second is the annual reappearance of the Antarctic ozone hole during the period around the Spring equinox, September in the southern hemisphere. The third is the long-term data concerning total ozone concentrations as recorded by ground-based Dobson instruments, and by the TOMS and SBUV instruments on the Nimbus 7 satellite since late 1978.

The Executive Summary of the Ozone Trends Panel has summarized the theoretical expectations and observations about ozone depletion in the upper stratosphere, as Key Findings Number 2.8 and 2.9:

2.8. "Theoretical calculations predict that local ozone concentrations near 40 km altitude should have decreased between 1979 and 1985 by 5 to 12% in response to the decrease in solar ultraviolet output and the increased atmospheric abundance of trace gases. This range represents the decreases predicted from the different models for the latitude belt 30°N to 60°N for all seasons."

2.9. "Analyses of satellite (SAGE) and ground-based (Umkehr) data taken since 1979 show small decreases in ozone concentrations; these

decreases peak near 40 km altitude with mean values of 3% and 9%, respectively. These observational values agree within the range of their errors."

In a related Key Finding, the Panel also concluded that stratospheric temperatures had decreased, as anticipated from loss of ozone in those altitudes, but not by an inexplicably large amount:

2.10. "Stratospheric temperatures between 45 and 55 km altitude have decreased globally by about 1.7 K since 1979, consistent with decreases in upper stratospheric ozone of less than 10%."

In summary then, the increased concentrations of trace gases, especially the chlorofluorocarbons (CFCs), are expected to cause a progressive depletion of ozone in the upper stratosphere; the lessened quantities of ozone are expected to absorb less ultraviolet radiation at those altitudes, and therefore to cause less heating, which in turn will result in lower temperatures in the upper stratosphere; and the experimental measurements to date indicate both less ozone around 40 km and lowered temperatures. The rate of depletion at 40 km is slow only in comparison with the enormous rates of ozone loss observed over Antarctica.

The Executive Summary of the Ozone Trends Panel made six Key Findings about Antarctic ozone, including these three:

2.12. "There has been a large, sudden, and unexpected decrease in the abundance of springtime Antarctic ozone over the last decade. Ozone decreases of more than 50% in the total column, and 95% locally between 15 and 20 km altitude have been observed."

2.15. "While the column ozone depletion is largest in the Antarctic springtime, ozone appears to have decreased since 1979 by 5% or more at all

latitudes south of 60 degrees south throughout the year."

2.17. "The weight of evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in ozone within the [Antarctic] polar vortex."

The evidence is very clear that large amounts of chlorine are being found as the free radical ClO in the Antarctic lower stratosphere. The presence of ClO demonstrates the existence of ozone-depleting chain reactions, and the amounts of chlorine found in the free radical form are larger than the total amounts of chlorine which were available in all chemical forms in the 1950s. These chain reactions are triggered by the first sunlight of the approaching Antarctic spring, and run almost un hindered for about five or six weeks, stripping air parcels in the 15 to 20 km altitude range of almost all of their ozone. The chemistry involved in this ozone depletion is facilitated by the presence in the frigid, dark Antarctic stratosphere of polar stratospheric clouds (PSCs), on whose surface chemical reactions can occur which transform stable chlorine reservoir molecules such as HCl and ClONO₂ into more photosensitive molecules such as Cl₂ and HOCl. This chemistry will eventually be described in full detail in the complete report of the Ozone Trends Panel, but has been outlined elsewhere earlier, as in my testimony to this committee on May 12, 1987. For use until the publication of the full report of the Ozone Trends Panel, I have attached a copy of the May 12 testimony, and add that the most important ozone removing process over Antarctica appears to involve the ClO dimer, as described by Molina and Molina (Journal of Physical Chemistry, 1987), and the needed high efficiency of PSCs for these heterogeneous chlorine reactions has been established by Molina et al. (Science, 1987).

Although the massive ozone depletions occur in the stratosphere over the Antarctic, the effects are not confined to Antarctic latitudes because the break-up of the winter polar vortex in mid-spring (not until late spring in 1987) sends very ozone-depleted air northward, a phenomenon now described as a "dilution effect" as the shortage of ozone over the Antarctic is spread across more northerly latitudes. This phenomenon is presumably an important contributor to the ozone decreases of 5% or more found in latitudes as far north as 50°N in some months. In this manner, the springtime Antarctic ozone depletions which did not exist in the 1960s, and which would not exist now except for the large concentrations of man-made chlorine compounds in the atmosphere, are not restricted in their potential effects to the latitudes in which the loss first occurred, but spread northward toward the populated areas of the southern hemisphere.

In 1986, Neil Harris and I began examining the ozone concentrations measured over Arusa, Switzerland (47°N, 9°E), as recorded in the official Ozone Data for the World compiled by the Atmospheric Environment Service in Toronto, Canada. We soon noticed the somewhat unexpected fact that marked decreases in ozone concentrations had occurred during several winter months, in contrast to such smaller changes found during the summer. We then checked Ozone Data for the World for changes in ozone concentrations over two other north temperate zone ground stations at the same latitude (Bismarck, North Dakota, and Caribou, Maine), and again found substantially different patterns between winter months and summer months, with large losses in the winter and relatively small losses in the summer. I have reproduced again in Figure 1 our calculations from the total ozone measurements recorded in Ozone Data for the World for the ground stations

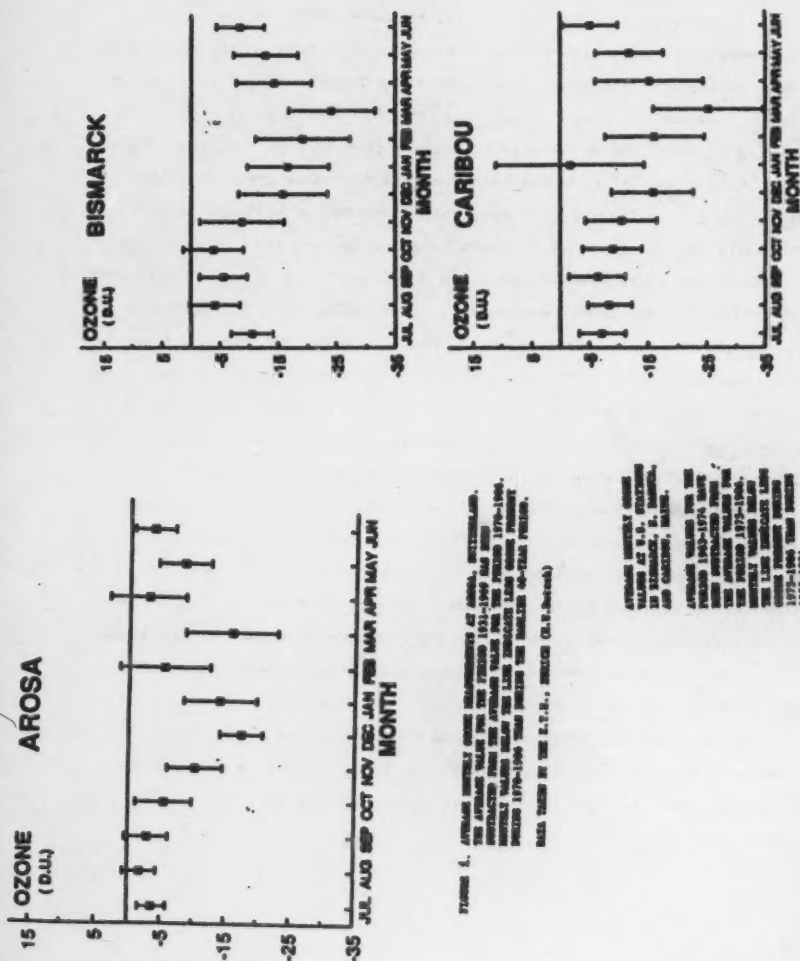


FIGURE 1. AVERAGE MONTHLY OZONE MEASUREMENTS AT AROSA, BISMARCK, AND CARIBOU. THE AVERAGE VALUES FOR THE PERIOD 1931-1949 HAS BEEN DETERMINED FROM THE AVERAGE VALUES FOR THE PERIOD 1970-1984. THE STANDARD DEVIATION FOR THE LONG PERIODS LONG RANGE FREQUENT MONITOR 1970-1984 THE PERIODS OF THE BISMARCK OF-THE PERIOD HAS BEEN TAKEN BY THE I.T.E., BRIDGE (D.R. Smith)

AVERAGE MONTHLY OZONE VALUES AT A.S. STATIONS IN BISMARCK, S. CARIBOU, AND CARIBOU, N.H.

AVERAGE VALUES FOR THE PERIOD 1931-1949 HAVE BEEN DETERMINED FROM THE AVERAGE VALUES FOR THE PERIOD 1970-1984. THE STANDARD DEVIATION FOR THE LONG PERIODS LONG RANGE FREQUENT MONITOR 1970-1984 THE PERIODS OF-THE PERIOD HAS BEEN TAKEN BY THE I.T.E., BRIDGE (D.R. Smith)

in Arosa, Bismarck, and Caribou. In all three of these stations, a pronounced indication exists for preferential depletion of ozone in the winter months. It should be added that these records extend back in time in each case for 22 years or more (i.e. for at least two solar cycles of 11 years each), with the Arosa data covering a continual period since August 1931. Upon examination of the recorded data from many other stations, Harris and I also found that almost all of the Dobson stations north of 30°N latitude showed negative trends in ozone for the mid-winter months.

One of the most important problems with these long series of data with ground-based Dobson spectrophotometers is the question of calibration. Dr. Rumen Bojkov of the Canadian Atmospheric Environment Service has examined with several techniques the consistency of the measurements for each station. One technique, as an illustration, involves the comparison of the ozone concentrations separately recorded when an instrument aboard the Nimbus 7 satellite is nearly overhead above a ground-based Dobson instrument. In this way, the satellite instrument serves during these overpasses as a "transfer standard" to detect problems with measurements by individual ground stations through intercomparison with the readings of the other ground stations on the same day. Dr. Bojkov has been able to detect inconsistencies in the recorded data from various stations in this manner, and to obtain improved long term data sets of ground-based ozone measurements. He has then gone further to combine such data sets from various stations into latitudinal band averages. Because the number of dependable ground-based stations south of 30°N latitude is quite limited, such data sets with good accuracy have been compiled only for the latitudes between 30°N and 64°N.

These monthly ozone averages for latitudinal bands have then been analyzed using standard multiple regression statistical techniques with the close cooperation of Dr. Peter Bloomfield of North Carolina State University to determine trends in ozone concentrations over time. The ozone concentrations can respond to the 11-year solar cycle, the 26 month quasi-biennial oscillation (QBO)*, to atmospheric nuclear testing around

* The direction of stratospheric winds over the equator shifts from easterly to westerly and back again about every 26 months, influencing in a cyclic manner the amounts of ozone found in particular latitudes.

1960-1961, and to the steady increases in the concentrations of the CFCs and other trace gases. When the data from 1965 through 1986 for these data from 1965 through 1986 for these latitude bands are tested for monthly trends, the results given in Table 1 were found. These data show strong preferences for ozone decreases in the winter months, and lesser decreases or even increases during the summer months. The winter/summer difference is larger for the latitudes further north. An important aspect of these observations is that the winter-time losses exceed those shown by current atmospheric model calculations. These models are also unable to handle the Antarctic ozone loss with quantitative success, and there is here a suggestion of similar failure in the northern hemisphere.

These results are summarized in two Key Findings:

2.3. "Analysis of data from ground-based Dobson instruments, after allowing for the effects of natural geophysical variability (solar cycle and the quasi-biennial oscillation (QBO)), shows measurable decreases from

TABLE 1

Coefficients of Multiple Regressions to
Re-analyzed Dobson Total Ozone Measurements
Collected into Band Averages
(total percent changes for period 1969-1986)*

MONTH	LATITUDE BAND		
	53°-64°N	40°-52°N	30°-39°N
JAN	- 8.3±2.2	- 2.6±2.1	- 2.2±1.5
FEB	- 6.7±2.8	- 5.0±2.2	- 1.2±1.9
MAR	- 4.0±1.4	- 5.6±2.3	- 3.5±1.9
APR	- 2.0±1.4	- 2.5±1.7	- 1.7±1.3
MAY	- 2.1±1.2	- 1.3±1.1	- 1.7±0.9
JUN	+1.1±0.9	- 1.8±1.0	- 3.3±1.0
JUL	+0.0±1.1	- 2.2±1.0	- 1.3±1.0
AUG	+0.2±1.2	- 2.4±1.0	- 1.0±1.0
SEP	+0.2±1.1	- 2.9±1.0	- 1.0±0.9
OCT	- 1.1±1.2	- 1.5±1.5	- 0.9±0.8
NOV	+1.5±1.8	- 2.4±1.3	- 0.1±0.8
DEC	- 5.8±2.3	- 5.5±1.7	- 2.1±1.1
ANNUAL AVERAGE	- 2.3±0.7	- 3.0±0.8	- 1.7±0.7
WINTER AVERAGE**	- 6.2±1.5	- 4.7±1.5	- 2.3±1.3
SUMMER AVERAGE***	+0.4±0.8	- 2.1±0.7	- 1.9±0.8
QBO*	- 2.0±0.6	- 1.3±0.6	+1.9±0.6
SOLAR*	+1.8±0.6	+0.8±0.7	+0.1±0.6

* per cycle minimum to maximum.

** winter months include December to March, inclusive.

*** summer months include June to August, inclusive.

+ All uncertainties given in this table and throughout this report represent one standard error. The total uncertainty in the linear trends for total column ozone (1969 - 1986) can be calculated by combining the standard errors given in this Table with a systematic error of 0.5% by taking the square root of the sum of their squares. The uncertainties shown in this Table increase by 0.2% or less.

1969 to 1986 in the annual average of total column ozone ranging from 1.7 to 3.0% at latitudes between 30 and 64 degrees in the northern hemisphere. The decreases are most pronounced, and ranged from 2.3 to 6.2%, during the winter months, averaged for December through March, inclusive. Dobson data are not adequate to determine total column ozone changes in the tropics, sub-tropics, or southern hemisphere outside Antarctica."

2.4. The [atmospheric] model calculations are broadly consistent with the observed changes in column ozone, except that the mean values of the observed decreases in mid and high latitudes in winter are larger than the mean values of the predicted decreases. The observed changes may be due wholly, or in part, to the increased abundance of trace gases, primarily chlorofluorocarbons (CFCs)."

The interplay between satellite and ground-based stations has two aspects, both of great utility. As described earlier, the day-to-day comparisons of ground stations using the satellite ozone data as the transfer standard are very helpful in identifying a ground station with a calibration problem. On the other hand, an important part of the TOMS and SBUV satellite instruments, the diffuser plate, is exposed systematically to direct unshielded solar radiation, and has undergone degradation during 9 years of such exposure on Nimbus 7. Corrections can be made for this deterioration in the instrument, but the Ozone Trends Panel has demonstrated that the precise magnitude of such corrections cannot be obtained from the satellite instrument alone. Comparison of overpass data for good ground stations allows evaluation of this degradation, which is now estimated as $-3.5 \pm 0.5\%$ over the period from 1978 to 1987. After the bias in the archived total column ozone data are corrected for this slow

drift in the satellite instruments, losses of ozone are still recorded for all latitude bands between 65°N and 65°S. (The satellite instruments require scattered sunlight, and do not provide winter-time measurements from the polar darkness.)

These changes in ozone concentrations as measured with the TOMS instrument on Nimbus 7 have been reported by the Ozone Trends Panel in Table 2. The data have been separately considered using measurements through October 1985, and through November 1987. The most recent maximum in the solar sunspot cycle came in the winter of 1979-1980, and the most recent minimum in mid-1986, with the next maximum expected about 1991. Therefore, the period from 1980 to mid-1986 was on the downside of the solar cycle, with an expectation of less solar ultraviolet radiation and therefore less ozone being formed, coupled with any changes in total ozone occurring from increasing concentrations of trace gases, especially the CFCs. The negative changes from November 1978 through October 1985 are attributable to a combination of natural decreases from the declining phase of the sunspot cycle, and to decreases from increasing concentrations of trace gases such as the CFCs.

The inclusion of data through November 1987 then adds in about 1.5 years of the rising phase of the sunspot cycle, during which the influences of the natural solar variability and the increases in man-made gases are expected to act in opposite directions. If the solar cycle is strong enough relative to the trace gas effect, then the time period from 1986 to 1991 could actually exhibit increasing amounts of ozone. The data of Table 2 suggest that a slight increase in ozone concentrations may have taken place between October 1985 and November 1987 in the northern hemisphere.

TABLE 2

TOMS TOTAL COLUMN OZONE CHANGES⁺

Latitude Band	Total Change From 11 / 78 - 10 / 85	Total Change From 11 / 78 - 11 / 87
53S - 53N	-2.6 ± 0.5	-2.5 ± 0.6
0 - 53S	-2.6 ± 0.9	-2.9 ± 0.9
0 - 53N	-2.1 ± 1.5	-1.8 ± 1.4
53S - 65S	-9.0 ± 1.8	-10.6 ± 1.6
39S - 53S	-5.0 ± 1.8	-4.9 ± 1.8
29S - 39S	-3.2 ± 2.4	-2.7 ± 2.1
19S - 29S	-2.5 ± 1.9	-2.6 ± 1.5
0 - 19S	-1.1 ± 0.8	-2.1 ± 0.8
0 - 19N	-1.1 ± 1.5	-1.6 ± 1.3
19N - 29N	-3.5 ± 2.2	-3.1 ± 1.9
29N - 39N	-3.7 ± 2.0	-2.5 ± 1.7
39N - 53N	-2.7 ± 1.7	-1.2 ± 1.5
53N - 65N	-2.4 ± 1.6	-1.4 ± 1.4

This analysis represents a linear trend using an autoregressive model through the normalized TOMS data.

+ All uncertainties given in this table represent one standard error.

In contrast, the data suggest that ozone concentrations in the southern hemisphere have continued to decrease slowly even on the rising phase of the solar cycle. After 1991, the expectation is that both the trace gas effect and the declining solar cycle would be acting in concert to decrease the average amount of stratospheric ozone.

Both the ground-based and satellite-borne ozone measuring systems have indicated a loss of ozone on a global basis over the past decade, with approximate agreement between them. At the present time, and for the foreseeable future, the best global ozone monitoring system must include both satellites and ground-based instruments. The global coverage from ground-based stations is not good because so many of these stations are concentrated in the northern quarter of the globe. However, the ground-based instruments are far more accessible for calibration and maintenance, and serve as "ground truth" for the satellite instruments to verify that any drift in their response to ozone can be satisfactorily corrected. With these regular calibrations against dozens of ground-based instruments, the satellite data can then provide good global coverage of all of the sunlit portions of the earth.

The initial Key Finding of the Ozone Trends Panel was concerned with the measurements of many important long-lived gases in the lower atmosphere:

2.1. "There is undisputed observational evidence that the atmospheric concentrations of source gases important in controlling stratospheric ozone levels (chlorofluorocarbons, halons, methane, nitrous oxide, and carbon dioxide) continue to increase on a global scale because of human activities."

The lifetimes of several of the CFCs can now be estimated with moderate accuracy from comparison of the amounts accumulating in the atmosphere versus the amounts released to it. Typical currently estimated atmospheric lifetimes for important chlorofluorocarbons are about 73 years for CCl_3F (CFC-11), 90-100 years for $\text{CCl}_2\text{FCClF}_2$ (CFC-113) and 110-140 years for CCl_3F_2 . Figures 2 and 3 show the concentrations of chain reacting chlorine available at 40 km altitude for releases of CCl_3F and CCl_3F_2 at exponential rates up to 1976, followed by constant yearly emissions through 1991, and then a hypothetical complete cessation of further emissions. The 40 km concentration of chlorine has been used in these Figures because the ClO_x chain is expected to be most effective at these altitudes in depleting stratospheric ozone over the tropical and temperate zones. With atmospheric lifetimes hovering around a century, substantial quantities of reacting chlorine are expected to remain in the stratosphere throughout both the 21st and 22nd centuries.

These atmospheric lifetimes can also be used to calculate the effects of the Montreal protocol in restricting emissions of CFCs to the atmosphere. Figure 4 demonstrates the anticipated increases in total atmospheric chlorine to the year 2010, with and without the restrictions of the Montreal protocol in effect. The atmosphere contained about 0.7 ppbv of chlorine in 1950, about 1.8 ppbv in 1974, about 3.5 ppbv in 1988, and is on its way, with or without the Montreal protocol restrictions, toward 5 ppbv in the year 2000. The graph in Figure 4 is actually quite conservative with respect to the protocol, because it assumes constant emissions at the 1986 level until 1994, a 20% decrease in 1994, and a further decrease of 30% for a total of 50% by 1999. The protocol permits

FIG. 3

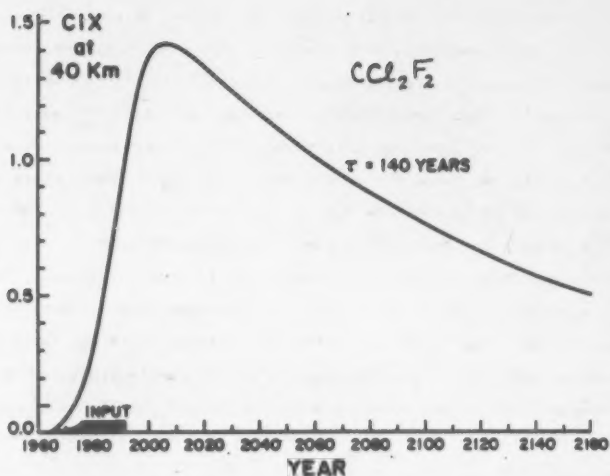
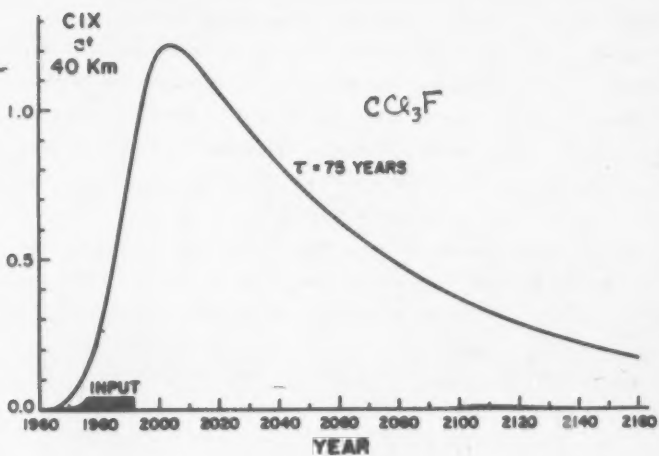


FIG. 2



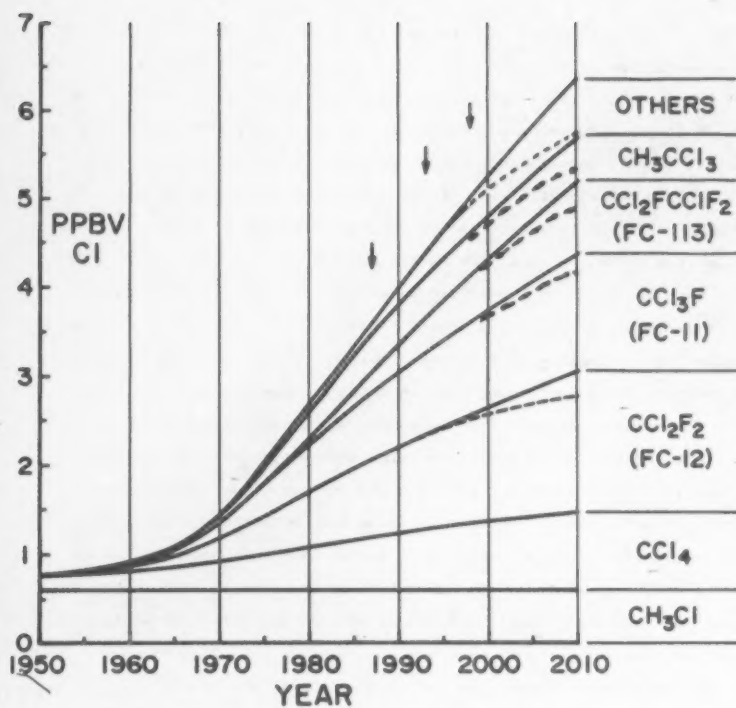


FIG. 4

increases in production and emission of CFCs above the 1986 level until 1990; some further expansion in production and emission of CFCs by the Soviet Union in fulfillment of its current 5-year plan; and a development period of 10 years during which countries not now having flourishing CFC capabilities could get started. When these increments are factored in, many calculate the actual effect of the cumulative provisions of the Montreal protocol to be approximately the equivalent of a "freeze" at 1986 emission levels--no increase, but no 50% cutback either.

The massive losses of ozone over Antarctica in September 1987 took place in air that was not fully equilibrated with the 1987 concentrations of organochlorine compounds, but instead was typical of air from about 10 years before. For this reason, even an instantaneous absolute ban today on further emissions of CFCs to the atmosphere would not prevent the ozone-depleting conditions over Antarctica from worsening into the 1990s. When less than the current 3.5 ppbv of chlorine has already shown itself capable of the immense destruction of ozone over Antarctica in September 1987, the increases in concentration to 5 ppbv which will quickly happen under the very mild restrictions scheduled for the next 12 years under the Montreal protocol will clearly not assure us that the Antarctic ozone hole is under control.

I was asked about a month ago in West Berlin, in the course of testimony to a fact-finding commission of the West German parliament, "What would be necessary to restore the stratosphere over Antarctica to the conditions prevailing in the 1960s?"

My answer was, "Install an immediate complete ban on further release of chlorine compounds to the atmosphere--and then wait 200 years." Actually,

examination of Figures 2 and 3 demonstrates that much longer than 200 years would be required to bring the stratosphere back to 1960 conditions with respect to reactive chlorine concentrations.

Statements were frequently made in connection with the September 1987 meeting which led to the Montreal protocol that the provisions were being designed without reference to any of the observations from the Antarctic ozone hole. The science background for the protocol included atmospheric model calculations which projected significant future global ozone losses only if CFC emissions were allowed to increase steadily. Since September, the chief cause of the Antarctic ozone losses has been unequivocally demonstrated to be traceable to man-made chlorine compounds. Since September, the existence of significant losses of stratospheric ozone in the northern winter has been demonstrated, more than can be accounted for by current theory. The existing atmospheric models are underestimating current ozone losses both in the northern winter and in the Antarctic spring. Under the circumstances, predictions of ozone change over the next few decades are of little use—how much reliance should be placed on a model for future predictions when it doesn't correctly mimic the present? Either of these unusual ozone loss phenomena is sufficient to show that the provisions of the Montreal protocol are too little and too late for any effective protection of stratospheric ozone during the coming decade. Together, they provide compelling reasons for moving rapidly toward the 95% phaseout of CFCs in much less than a decade which was the official U.S. position a year ago, and which is called for by legislation currently being considered by this committee.



Hold for Release Until
Presented by Witness

March 30, 1988

**Subcommittee on Hazardous Wastes
and Toxic Substances
Subcommittee on Environmental Protection
Committee on Environment and
Public Works**

United States Senate

Statement by:

**Dr. Robert T. Watson
Earth Sciences and Applications
Division
Office of Space Science and
Applications**



100th Congress

STATEMENT OF
DR. ROBERT T. WATSON
OFFICE OF SPACE SCIENCE AND APPLICATIONS
BEFORE THE
SUBCOMMITTEES ON
HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND
ENVIRONMENTAL PROTECTION
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
U. S. SENATE

Mr. Chairmen and Members of the Subcommittee:

I am pleased to be here today to discuss the current status of knowledge concerning the Earth's protective ozone layer. I will focus most of my attention on the scientific findings from the recent report of the international "Ozone Trends Panel" that I chaired. My written testimony includes:

- (A) A brief summary of certain aspects of the scientific basis of the "Montreal Protocol."
- (B) The executive summary of the "Ozone Trends Panel" report;
- (C) The Antarctic Ozone chapter summary;
- (D) Theoretical Predictions; and
- (E) Summary.

This approach should enable you to see changes in our scientific understanding since the Montreal Protocol was signed in September 1987 and was ratified by the Senate on March 14, 1988.

(A) SCIENTIFIC BASIS OF MONTREAL PROTOCOL

- 1) The ozone issue and the greenhouse warming issue are strongly coupled because ozone itself is a greenhouse gas, and because the same gases that are predicted to modify ozone are also predicted to produce a climate warming. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several chlorofluorocarbons (CFCs) and halons (bromine containing compounds).
- 2) There was compelling observational evidence that the chemical composition of the atmosphere was changing at a rapid rate on a global scale. The atmospheric concentrations of CO_2 , CH_4 , N_2O , and CFCs 11 and 12 were increasing at rates ranging from 0.2 to 5.0% per year. These changes in atmospheric composition reflected in part the metabolism of the biosphere and in part a broad range of human activities.

- 3) One dimensional model calculations were performed to predict how ozone would change with time assuming that the atmospheric concentrations of CO_2 , CH_4 , and N_2O , continued to increase at their current rates of 0.5%, 1.0%, and 0.2 % per year, respectively, for the next 100 years, in conjunction with three different assumptions for the annual growth rates in the emission of CFCs 11 and 12 to the atmosphere, i.e. 0.0%, 1.5%, and 3.0%. For a constant CFC emission rate (no growth) the ozone column changes were calculated to be less than one percent over the next 100 years. With a CFC growth rate of 3.0% per year, the predicted ozone depletion was 10% after 70 years and rapidly increasing.
- 4) One dimensional model calculations showed that even when the predicted column ozone changes were small (less than 1%), major changes (about 25% depletion near 40 km altitude) in the vertical distribution of ozone were still predicted. Ozone was predicted to decrease in the middle and upper stratosphere due primarily to the increasing atmospheric concentrations of CFCs, and to increase in the lower stratosphere and troposphere due primarily to the increasing atmospheric concentrations of CH_4 .
- 5) Two dimensional model calculations predicted a significant variation in the ozone column decreases with latitude with the greatest depletions occurring at high latitudes. In general, two dimensional model calculations predicted somewhat greater amounts of ozone depletion for the same trace gas scenarios than did one dimensional calculations. One two dimensional model using the no growth scenario for CFCs predicted a global average ozone depletion of about 2% during the next 50 to 70 years with a depletion of 1.5% at the equator, 2% at 30°N , and up to 4% at 60°N .
- 6) In general, analyses for the trends in the total global column content of ozone using data from the ground-based Dobson network showed no statistically significant trend since 1970, in agreement with one dimensional model predictions for the same period when the changes in all of the trace gases were taken into account.
- 7) Trend estimates were also made for the altitude profile of ozone from the network of stations using the Umkehr technique. After correcting the derived ozone amounts for the aerosol interference, an estimate of the ozone trend in the middle and upper stratosphere (30 to 40 km altitude) gave a 2 to 3% decrease for the period 1970 to 1980. The magnitude of the change was broadly consistent with the predictions of photochemical models that predicted that chlorine would have its maximum effect at this altitude.
- 8) A preliminary analysis of Nimbus 7 satellite Solar Backscatter Ultraviolet (SBUV) data indicated that there had been a statistically significant decrease in both the total column content (about 1% per year) and the amount of ozone in the middle and upper stratosphere with the depletion being a maximum near 50 km altitude (about 3% per year) between late 1978 and late 1984. At that stage it was deemed crucial to evaluate whether the data had been interpreted correctly, and if so, whether the decrease was due to natural causes such as a decrease in solar ultraviolet radiation, the 1982 volcanic eruption of El Chichon, the 1982 El Nino event, or whether it was due to human activities such as the use of CFCs. At that time any of these explanations were viewed as plausible.
- 9) Ground-based and satellite data had demonstrated that ozone in springtime over Antarctica had decreased significantly since the mid 1970's, and that the decreases were not just confined to an area above Antarctica but extended from the South Pole to about 45°S . Both chemical and dynamical explanations had been advanced to explain the observations. While it had been suggested that these Antarctic ozone decreases were caused by increasing atmospheric concentrations of chlorine in the stratosphere, no credible mechanism had been demonstrated.

(B) THE OZONE TRENDS REPORT

L0 INTRODUCTION

In 1985 two important reports of changes in atmospheric ozone were released. The first report was of a large, sudden, and unanticipated decrease in the abundance of springtime Antarctic ozone over the last decade. The second report, based on satellite data, was of large global-scale decreases since 1979 in both the total column content of ozone and in its concentration near 50 km altitude. In October of 1986, the National Aeronautics and Space Administration (NASA), in collaboration with the National Oceanic and Atmospheric Administration (NOAA), the Federal Aviation Administration (FAA), the World Meteorological Organization (WMO), and the United Nations Environment Program (UNEP), formed an Ozone Trends Panel, that involved over one hundred scientists, to study the question of whether carefully re-evaluated ground-based and satellite data would support these findings. This report critically assesses our present knowledge of whether the chemical composition and physical structure of the stratosphere has changed over the last few decades and whether our current understanding of the influence of natural phenomena and human activities is consistent with any observed change. This report is different from most previous national and international scientific reviews in that we did not simply review the published literature, but performed a critical reanalysis and interpretation of nearly all ground-based and satellite data for total column and vertical profiles of ozone. To aid in the interpretation of the results of this re-analysis we also performed a series of theoretical calculations for comparison with the reanalyzed ozone data. In addition, a uniform error analysis was applied to all the data sets reviewed that contained information on the vertical ozone distribution.

2.0 KEY FINDINGS

Source and Trace Gases

(1) There is undisputed observational evidence that the atmospheric concentrations of source gases important in controlling stratospheric ozone levels (chlorofluorocarbons, halons, methane, nitrous oxide, and carbon dioxide) continue to increase on a global scale because of human activities.

Global Ozone

(2) Calculations using two-dimensional photochemical models predict that increasing atmospheric concentrations of trace gases would have caused a small decrease in ozone globally between 1969 and 1986. Predicted decreases between 30 and 60 degrees latitude in the northern hemisphere for this period ranged from 0.5 to 1.0% in summer and 0.8 to 2.0% in winter, where the range reflects the results from most models.

(3) Analysis of data from ground-based Dobson instruments, after allowing for the effects of natural geophysical variability (solar cycle and the quasi-biennial oscillation (QBO)), shows measurable decreases from 1969 to 1986 in the annual average of total column ozone ranging from 1.7 to 3.0%, at latitudes between 30 and 64 degrees in the northern hemisphere. The decreases are most pronounced, and ranged from 2.3 to 6.2%, during the winter months, averaged for December through March, inclusive. Dobson data are not adequate to determine total column ozone changes in the tropics, sub-tropics, or southern hemisphere outside Antarctica.

(4) The model calculations are broadly consistent with the observed changes in column ozone, except that the mean values of the observed decreases at mid and high latitudes in winter are larger than the mean values of the predicted decreases. The observed changes may be due wholly, or in part, to the increased atmospheric abundance of trace gases, primarily chlorofluorocarbons (CFCs).

(5) Satellite instruments on Nimbus 7 (Solar Backscatter Ultraviolet (SBUV) and Total Ozone Mapping Spectrometer (TOMS)) have provided continuous global records of total column ozone since October 1978. Unfortunately they suffer from instrumental degradation of the diffuser plate, the rate of which cannot be uniquely determined. Thus, the data archived as of 1987 cannot be used alone to derive reliable trends in global ozone.

(6) The SBUV and TOMS satellite data have been normalized by comparison with nearly coincident ground-based Dobson measurements in the northern hemisphere. The resulting column ozone data, averaged between 53 degrees south and 53 degrees north latitudes, show a decrease of about 2.5% from October 1978 to October 1985. This period is approximately coincident with the decrease in solar activity from the maximum to the minimum in the sunspot cycle.

(7) Theoretical calculations predict that the total column ozone would decrease from solar maximum to solar minimum by an amount varying between 0.7 and 2% depending upon the model assumed for solar ultraviolet variability. Thus, the observed decrease in ozone from the satellite data between late 1978 and late 1985 is predicted to have a significant contribution from the decrease in solar activity during this period.

(8) Theoretical calculations predict that local ozone concentrations near 40 km altitude should have decreased between 1979 and 1985 by 5 to 12% in response to the decrease in solar ultraviolet output and the increased atmospheric abundance of trace gases. This range represents the decreases predicted from the different models for the latitude belt 30° to 60°N for all seasons.

(9) Analyses of satellite (SAGE) and ground-based (Umkehr) data taken since 1979 show small decreases in ozone concentrations; these decreases peak near 40 km altitude with mean values of 3 and 9%, respectively. These observational values agree within the range of their errors.

(10) Stratospheric temperatures between 45 and 55 km altitude have decreased globally by about 1.7K since 1979, consistent with decreases in upper stratospheric ozone of less than 10%.

(11) Thus, this assessment does not support the previous reports based on SBUV and TOMS data^{1,2} of large global decreases since 1979 in the total column of ozone (about 1% per year) or in the ozone concentration near 50 km altitude (about 3% per year). These reports used data archived as of 1987, and the trends obtained were erroneously large because of unjustified and incorrect assumptions about the degradation of the diffuser plate common to both the SBUV and TOMS satellite instruments.

Antarctic Ozone

(12) There has been a large, sudden, and unexpected decrease in the abundance of spring-time Antarctic ozone over the last decade. Ozone decreases of more than 50% in the total column, and 95% locally between 15 and 20 km altitude have been observed.

- (13) The total column of ozone in the Austral spring of 1987 at all latitudes south of 60 degrees south, was the lowest since measurements began 30 years ago.
- (14) In 1987 a region of low column ozone over Antarctica lasted until late November - early December, which is the longest since the region of low ozone was first detected.
- (15) While the column ozone depletion is largest in the Antarctic springtime, ozone appears to have decreased since 1979 by 5% or more at all latitudes south of 60 degrees south throughout the year.
- (16) The unique meteorology during winter and spring over Antarctica sets up the special conditions of an isolated air mass (polar vortex) with cold temperatures required for the observed perturbed chemical composition.
- (17) The weight of evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in ozone within the polar vortex.

3.0 SOURCE AND TRACE GASES

There is undisputed observational evidence that the atmospheric concentrations of a number of the gases that are important in controlling atmospheric ozone and climate are increasing at a rapid rate on a global scale because of human activities. Such gases include nitrous oxide (N_2O), methane (CH_4), carbon tetrachloride (CCl_4), methyl chloroform (CH_3CCl_3), and several chlorofluorocarbons (CFCs) and halons (bromine-containing compounds, e.g. CBrF_3 , CBrClF_2). These gases are important sources of the stratospheric nitrogen, hydrogen, chlorine, and bromine species that are predicted to photochemically control the abundance of ozone. The increasing atmospheric concentration of carbon dioxide (CO_2) is also predicted to affect the abundance of stratospheric ozone, but indirectly, by modifying the temperature structure of the atmosphere and hence the rates of ozone destruction.

Ground-based measurements of hydrochloric acid (HCl) and hydrofluoric acid (HF) indicate that, between 1976 and 1987, their column abundances increased annually by rates of 2-3 % for HCl and 5-10% for HF . Within the limits of experimental uncertainty, these rates are consistent with those expected from the increased tropospheric abundances of their source gases that contain chlorine and fluorine. There are currently an insufficient number of measurements of the chlorine monoxide radical (ClO) to determine an accurate trend in this key stratospheric ozone-altering species.

A critical analysis of all nitrogen dioxide (NO_2) data from ground-based, aircraft and satellite instruments indicates that, if there has been any increase in NO_2 at all since 1979, it is less than 20%. Therefore, this assessment cannot support the recent report³ of an approximately 60% increase in the stratospheric abundance of NO_2 between 1979 and 1986.

4.0 TOTAL COLUMN OZONE

Total column ozone measurements have been made for more than 30 years at many locations around the world using ground-based Dobson spectrophotometers. Satellite measurements suitable for detecting long-term changes in ozone began only in the late 1970's. Hence, at present, long-term changes and trends over decades can only be assessed using ground-based data. However, changes since late 1978 may be examined using both ground-based and satellite data. This assessment found that all of the ground-

based and satellite data had to be critically reanalyzed before being used for the accurate determination of trends. The Dobson data were re-analyzed taking more fully into account instrument calibration changes. Furthermore, data from certain stations were deemed unusable because of questionable quality. The accuracy of the reevaluated data from a "good" Dobson station is estimated to be better than 0.7% per decade.

The quantity and quality of ground-based observations in the tropics and subtropics are such that the determination of trends is far less precise there than for northern midlatitudes. In addition, reliable data are sparse in the southern hemisphere outside of Antarctica. Thus, the Dobson data are not adequate to determine total column ozone changes in the tropics, sub-tropics, or southern hemisphere. The satellite data, while providing global coverage, are affected by long-term drifts in instrument calibration. The ground-based stations furnish these needed calibration standards for assuring stable performance in the satellite assessment of contemporary global changes in total column ozone. In this report, the determination of such changes since 1979 was made using satellite data normalized against the Dobson data.

Comparisons were made between simultaneous measurements of total column ozone by ground-based Dobson stations and by the SBUV and TOMS instruments on the Nimbus 7 satellite. These show that the column ozone amounts derived from satellite data have drifted downward with respect to the values derived from Dobson measurements by $3.5 \pm 0.5\%$ in the nine year period since the launch of the instruments in October 1978. An accurate determination of the trend in total column ozone using SBUV or TOMS data alone requires precise knowledge of the rate of degradation of the diffuser plate, which is a key optical component shared by both instruments. An incorrect estimate of the magnitude of the wavelength dependence of the degradation manifests itself as an erroneous change in ozone. There is insufficient information from the instruments themselves to determine this, and a model of the diffuser plate degradation had to be assumed in the production of the SBUV and TOMS data sets archived as of 1987. We find that this model is not unique, and that there is a wide range of models consistent with the available diffuser plate information. Consequently, we conclude that it is not possible to obtain a sufficiently accurate trend in total ozone using Nimbus 7 satellite data alone because the rate of degradation of the diffuser plate cannot be uniquely determined. Therefore, the ozone trends reported based on archived SBUV and TOMS data^{1,2} cannot stand alone as a unique data set. The data can, however, be normalized by comparisons with ground-based instruments and then used for trend determinations, as is described in section 4.2.

4.1 Total Column Ozone Changes Since 1960 Derived Using Ground-Based Dobson Data

4.1a Statistical Analysis of Data

Total column ozone abundances at individual ground-based stations are known to be affected by at least three natural cyclic geophysical changes, namely the annual cycle of the seasons, the quasi-biennial oscillation (QBO) of the stratospheric winds with a repeating cycle of about 26 months, and the 11-year solar sunspot cycle. There might also be natural effects from other irregular transient phenomena, such as the El Nino Southern Oscillation (ENSO), or sporadic events such as volcanic eruptions. In addition, strong theoretical reasons exist for believing that the injection of the oxides of nitrogen from the atmospheric nuclear bomb tests of the late 1950's and early 1960's caused a reduction in total column ozone at that time. A statistical analysis of the ground-based ozone data from the Dobson stations was made to assess whether, after allowance for the perturbations from seasonal cycles, the QBO, the solar sunspot cycle, and nuclear tests, a residual linear trend existed in the measurements after 1970. Any residual trend can then be compared to theory to test our

understanding of the impact of the increased abundance of trace gases or other poorly understood natural phenomena such as the effects of the volcanic eruption of El Chichon.

The analysis of the ground-based ozone data can be carried out either through examination of the individual results on a station-by-station basis or by averaging the data over broad latitudinal bands in the northern hemisphere where sufficient high quality data are available. Both procedures have been used to analyze the data for the period 1965 to 1986. The scarcity of ground stations with long verified records make latitudinal band averages for the sub-tropics and southern hemisphere less reliable. Table 1 shows the magnitude of the residual linear trends for individual months that correspond to ozone changes since 1969 over several latitude zones with the effects of the QBO and solar cycle effects removed. The data were also analyzed using only those values measured before the volcanic eruption of El Chichon and the large ENSO event of 1982. The residual linear trends obtained from this analysis were not significantly different from those obtained using data through 1986. Based on this result it appears that the trends are not significantly affected by these natural events. The magnitude of the QBO and solar cycle effects are shown at the bottom of Table 1. The standard errors shown in Table 1 should be combined with an estimated systematic error for each latitude belt, which would be undetected by the statistical regression procedure, of 0.3% per decade (0.5% for period 1969 to 1986). This would increase the magnitude of the standard errors shown in Table 1 by about 0.2% or less.

The correlation of ozone change with the QBO is known to be dependent on latitude and this conclusion is confirmed in Table 1. The ozone response to the solar cycle varies from negligible to about 2% peak-to-peak for different latitude belts, with the largest column ozone occurring at the sunspot maximum (winter 1979-1980). The remaining linear trends show that there has been a measurable decrease in the annual average total column ozone of 1.7 to 3.0% in all latitude bands from 30 to 64 degrees in the northern hemisphere from 1969 to 1986 (Table 1). The decreases are largest during the winter months (2.3 to 6.2%), averaged for December through March, inclusive. These contrast to the smaller changes in column ozone during the summer months (+0.4 to -2.1%), averaged for June through August, inclusive. Although there are insufficient stations to determine an accurate trend in the latitudinal band average of total column ozone at latitudes higher than 64°N the limited data suggest that there has been a decrease comparable in magnitude to that observed between 53° and 64°N. It should be noted that there are observational balloon-sonde data suggesting that tropospheric ozone may have increased at mid-latitudes in the northern hemisphere by as much as 1% per year over the last twenty years. Because about one tenth of the total column ozone is in the troposphere this would be equivalent to an increase in total column ozone of about 2%, possibly offsetting a decrease in stratospheric ozone. The reliability and hemispheric significance of these tropospheric data is currently a subject of debate.

Theoretical calculations of the expected changes in the total column ozone over the last thirty years were performed especially for this study. These calculations were carried out using two-dimensional models, which predict ozone changes with season and latitude. These calculations took into account variations in the solar output, the input of the oxides of nitrogen due to the nuclear bomb tests around 1960, and the increase in trace gas abundances, but they could not take into account the impact of the QBO, the ENSO, or the 1982 volcanic eruption of El-Chichon since there is inadequate understanding of how to model the various possible associated effects. These calculations predict that the total column ozone should have varied over the solar cycle by at least 0.7% and up to 2% and should have decreased between 30° - 60°N by about 0.5 to 1.0% in summer and 0.8 to 2.0% in winter from 1969 to 1986 in response to the increased abundances of trace gases. One model predicts anomalous increases to summertime total column ozone that are

inconsistent with other model results. The calculated changes in total column ozone caused by variations in solar output are broadly consistent with those observed. However, while the predicted decreases in total column ozone caused by the increased abundances of trace gases are consistent with the observed decreases in summer, the mean values of the predicted decreases are less than the mean values of the observed decreases in winter, especially at high latitudes. The residual linear trends in total column ozone might be caused wholly, or in part, by the increased abundance of trace gases, primarily CFCs.

4.1b Comparison of Two Consecutive 11-Year Solar Cycle Periods

The Dobson data were subjected to a second type of analysis. Namely, the change in total column ozone between two consecutive 11-year solar cycles, i.e. 1965-1975 and 1976-1986 inclusive, was assessed. This analysis has the advantage that averaging over 11-year time periods reduces ozone changes attributable to variations in solar output and the QBO. Measured changes in ozone between the two periods can then be compared to theoretical predictions of the effects due to increases in the abundance of the trace gases, primarily CFCs. The ground-based Dobson measurements of the total column ozone show an average decrease of $1.4 \pm 0.7\%$ between the periods 1965-1975 and 1976-1986 in the 30° - 60° N latitude zone. This decrease was not uniform throughout the year, but was smaller in summer, $0.5 \pm 0.6\%$, and larger in winter, $2.5 \pm 1.0\%$. The decrease was also not uniform with latitude in winter, but was largest at high latitudes.

Model calculations of the expected changes in the total column ozone caused by an increase in the abundance of the trace gases between these same two periods predict greater depletions at mid and high latitudes in winter than in summer. The predicted decreases for the summer period (0.2 to 0.6%) are similar to those obtained from the Dobson data. Total column ozone was calculated to decrease in winter between these two time periods by about 0.5% at 30° N and about 1.0% at 60° N: these predicted decreases are less than half as large as the observed decreases during the winter period at mid to high latitudes.

4.2 Total Column Ozone Changes From Late 1978 to Late 1985 Using Satellite Data

As we have emphasized in this report, there is no way to correct the SBUV and TOMS measurements of total column ozone without comparison to other more stable records, such as Dobson measurements. One of the several possible models of the degradation of the SBUV diffuser plate that is consistent with available diffuser information leads to satellite total column ozone measurements that show no drift in time with respect to the ground-based measurements made when the satellite passed almost directly over the ground stations. Because the Dobson data are believed to be stable to better than 0.5% over the period 1979 to 1987, we decided to normalize the SBUV and TOMS total ozone data to the mid-latitude northern hemisphere Dobson data. This normalization procedure assumes that there is no significant latitudinal bias in the satellite degradation. The normalized TOMS satellite data show a decrease of total column ozone between October 1978 and October 1985 in all latitude zones in both the northern (1.1 to 3.7%) and southern (1.1 to 9.0%) hemispheres, as shown in Table 2.

As noted, model calculations of total column ozone from 1979 to 1985 predict a decrease caused both by the increased abundance of trace gases and by the declining phase of the solar cycle. In response to the observed increase in trace gases, the models predict that the total column ozone should have shown a greater decrease at mid to high latitudes in winter (0.5 to 1.5%) than in summer (0.2 to 0.6%). The impact of decreasing solar output on total column ozone is predicted to be relatively invariant with latitude and season, and the

range of predicted decreases varies from 0.7 to 2.0% over this period. Thus, the solar cycle may have had a comparable or larger impact on total column ozone than that of the trace gases over the period 1979 to 1985. Because of the short time period covered by the satellite data, less than one solar cycle, it is difficult to separate unambiguously the effects of solar variability and increased trace gas abundance on ozone. The predicted change in total column ozone in the northern hemisphere is broadly consistent with the observations for the period 1979 to 1985, although the satellite measurements possibly suggest largest changes at mid-latitudes whereas the models predict largest changes at high latitudes. The models do not have the ability to simulate the spring-time Antarctic ozone hole phenomenon and its possible impact at other seasons and latitudes in the southern hemisphere. Consequently, a comparison between observed and calculated changes in the southern hemisphere must be interpreted with caution. Because of the short time period and relatively small changes in ozone, a more detailed analysis of the accuracy of the measured data is required before any firm conclusions regarding a discrepancy between theory and observations can be drawn.

4.3 Predicted Changes For Total Column Ozone From 1986 Through 1991

The next maximum in the solar sunspot cycle is expected in 1991, and theoretical calculations predict that the natural response of ozone to this cycle will be to increase toward a maximum at that time. During the 1986-1991 time period, this natural response to the solar cycle may offset or even reverse the predicted decrease in total column ozone that would be due to the increasing abundances of atmospheric trace gases alone. With the possible exception of high latitude winter, where decreases may continue to be evident, total column ozone is predicted to exhibit very little change or small increases up to 1991. After 1991, when the solar ultraviolet output begins to decline, the total column ozone is again predicted to decrease.

Comparison of the normalized TOMS satellite data given in columns 2 and 3 in Table 2 suggests that total column ozone, as predicted, has not continued to decrease in the northern hemisphere since passing the solar minimum in 1986 and the very intensive QBO of 1985. However, the rate of change of total column ozone averaged over the southern hemisphere appears to have remained more constant through 1987, possibly because of the additional ozone losses associated with the Antarctic ozone hole phenomenon, especially in high latitudes in the southern hemisphere. A meaningful interpretation of the observations must await more data.

5.0 VERTICAL DISTRIBUTION OF OZONE

The vertical distribution of ozone has been measured globally using several satellite instruments including the Nimbus 7 SBUV instrument, the Stratospheric Aerosol and Gas Experiment (SAGE) I and II visible spectrometers, and the Solar Mesospheric Explorer (SME) infra-red and ultra-violet spectrometers. Long-term ground-based measurements of ozone up to altitudes of 50 km are restricted to just a few locations around the world using the Umkehr technique at Dobson Stations. As in the case of the total column ozone data, the vertical ozone profile data had to be fully reanalyzed before using them to assess changes or derive small trends. These reanalyzed data were used to evaluate changes in the vertical distribution of ozone since the late 1970's and were compared to the model simulations of the period 1979 to 1986 described above.

Our analysis of the different satellite data sets suggest that the determination of changes in the vertical distribution of ozone currently obtained using SAGE I and SAGE II data are the least sensitive to changes in the performance of the instruments over time. These data were combined to set limits on a possible ozone decrease in the altitude range 25 to 50 km in

both the 20° to 50° N and 20° to 50° S latitude belts between the periods 1979-1981 and 1985-1987. At an altitude of 40 km, this change had a mean value of -3% with a standard error of about 1% and a possible systematic error of 4%. Consequently, the change in ozone near 40 km is between +1% to -7%. The SAGE data also indicate a decrease in ozone near 25 km that is comparable in magnitude to that observed near 40 km. However, the SAGE data show no change, $0 \pm 1\%$, (+4% to -4%, including the possible systematic error) near 50 km.

An earlier analysis¹ of the SBUV data archived as of 1987 suggested that the vertical distribution of ozone changed dramatically between late 1979 and 1985 with a decrease of over 20% occurring near 50 km altitude. However, the determination of the vertical distribution of ozone from SBUV is even more dependent upon the corrections applied for the degradation of the diffuser plate than is the determination of total column ozone. The reported analysis¹ used data derived with the same SBUV diffuser plate model that was later found to be unsuitable for reliable determination of changes in total column ozone. A diffuser plate model that eliminates the bias between the SBUV and Dobson measurements of total column ozone also leads to a change in the ozone distribution that shows an increase near 50 km altitude, with a decrease that peaks at about 7% near 40 km altitude. Because of the arbitrary assumptions and uncertainties in the model, the results should be regarded as only suggestive, although generally supporting the SAGE I - SAGE II differences.

Measurements at low sun angles with the ground-based Dobson instrument (Umkehr technique) can be used to estimate the vertical distribution of stratospheric ozone. The Umkehr method suffers from the difficulties of the Dobson instrument, and the Umkehr measurements require a higher degree of operator skill. In addition, there are only a small number of Umkehr stations with an extended record, some stations suffer from sparse data records and have periods of noisy data, and the "Umkehr technique" is very sensitive to the presence of stratospheric aerosols because these particles affect the transmission of the ultraviolet radiation used for the ozone measurements. The volcanic eruption of El Chichon in April of 1982 injected very large quantities of dust into the stratosphere, causing major interferences with attempts to apply the Umkehr technique for the determination of vertical ozone profiles. Theoretically, corrections for aerosol contamination can be made to the Umkehr data, but only if the atmospheric abundance, size distribution, and optical properties of the aerosols are accurately known. Therefore, the historical Umkehr record is questionable during volcanically disturbed periods because instrumentation for aerosol measurements has only recently begun to be installed at some of the locations where Dobson Umkehr measurements have been taken. Umkehr data from five northern mid-latitude stations, corrected using the best available data and theory for the effect of volcanic aerosols, suggest that ozone decreased between 1979 and 1986 by $8 \pm 3\%$, and $9 \pm 4\%$, at altitudes between 33-38 km (Umkehr level 7) and 38-43 km (Umkehr level 8), respectively. The uncertainty estimate includes the one standard uncertainty for random errors and a term for the uncertainty in the aerosol corrections, but there is no term for possible systematic errors. The decrease in ozone near 40 km is consistent within the stated experimental uncertainties with that obtained using SAGE I and SAGE II data, (and the SBUV data that has been corrected approximately for a diffuser plate model with more degradation), but is smaller than the decrease obtained using the SBUV data archived as of 1987. Because of the small number of stations, these figures cannot be regarded as a global estimate nor even as an average for the northern mid-latitude zone. Although an aerosol correction can be applied to the Umkehr data, concern remains due to the unquantified sensitivity of the analysis to the assumed aerosol properties, particularly following major volcanic eruptions. The Umkehr technique cannot be used as a primary

tool for the continuous monitoring of the vertical distribution of ozone because of the several limitations cited above.

The analysis of stratospheric temperature trends can also be used to assess ozone changes in the upper stratosphere because the absorption of ultraviolet radiation by ozone is the primary heat source. A critical analysis of stratospheric temperature data from a variety of sources show a greater consistency than previously believed. Satellite radiance measurements corresponding to an altitude range from 45 to 55 km show a decrease in stratospheric temperature from 1979 to 1986 of $1.7 \pm 1\text{K}$ globally, and $1.3 \pm 1\text{K}$ in the tropics. If the archived SBUV data that indicated an ozone decrease of 20% near 50 km are inserted into radiative transfer models, satellite-measured temperature changes of -4 to -5K are predicted. The observed temperature changes are substantially less than the predicted values, providing an indirect confirmation that the SBUV data archived as of 1987 do not provide a reliable estimate of changes in ozone in the upper stratosphere. The observed temperature changes are, however, broadly consistent with those determined using SAGE I and II ozone data, and those predicted by the theoretical photochemical models ($-1.8 \pm 0.4\text{K}$ between 45 and 55 km altitude).

Therefore, the weight of observational evidence from SAGE, Umkehr, and temperature data thus indicates that the reported 50 km ozone decreases between 1979 and 1985 that were based on SBUV data archived as of 1987 cannot be supported. We conclude that these large SBUV ozone trends are a result of unjustified and incorrect assumptions about the degradation of the diffuser plate.

As noted, predicted changes in the vertical distribution of ozone over the period 1979-1985 indicate a maximum depletion near 40 km. Ozone near 40 km is predicted to have decreased by 5 - 12%: a 4 - 9% decrease in response to the increased abundances of the trace gases, and a 1 - 3% decrease in response to the reduced solar ultraviolet output over the time period. These ranges represent the decreases predicted from the different models for the latitude belt 30° to 60°N for all seasons. According to the theoretical models, the dominant effect due to trace gases over this period comes from the increase in the atmospheric abundance of CFCs. These predicted changes in ozone are consistent with the observations, although somewhat greater than the mean value obtained using SAGE I and SAGE II data. In particular, the overall shape of the predicted changes in the vertical distribution of ozone is consistent with the SAGE data.

Unambiguous separation of the impact upon the vertical distribution of ozone by the two major perturbations, solar cycle and trace gases, awaits continued observation over the remainder of this solar cycle and perhaps beyond. Model forecasts for the period 1985 - 1991, as we approach the next solar maximum, predict that ozone near 40 km will continue to decrease as a result of increases in stratospheric chlorine, despite the rise in solar ultraviolet output, which by itself would lead to an increase in ozone amounts.

6.0 THE ANTARCTIC OZONE PHENOMENON

Ground-based and satellite data have shown conclusively that the spring-time Antarctic column ozone decreased rapidly after the late 1970's. The high degree of interannual variability and the lack of satellite based ozone measurements precludes an accurate assessment of the magnitude of any ozone decreases prior to the late 1970's. The Antarctic ozone hole develops primarily during September, and the rate of loss of ozone within a given year appears to be increasing. Total column ozone (at all latitudes south of 60° degrees) was lower in the Antarctic springtime in 1987 than in any previous year since satellite measurements began (late 1978). In October 1987, the monthly zonal mean

amount of total ozone at latitudes 60, 70, and 80 degrees south was about 20%, 40%, and 50% lower, respectively, than in October 1979. In 1987, a region of low ozone over Antarctica lasted until late November / early December, which is the longest since the region of low ozone was first detected. While the ozone depletion is largest in the Antarctic spring-time, normalized TOMS data indicate that total column ozone has decreased since 1979 by more than 5% at all latitudes south of 60 degrees throughout the year. At this time it is premature to judge if this is caused by a dilution of the air from the region of very low ozone, a changed meteorology, or some other unidentified phenomenon. However, at least some of the decrease is likely due to dilution. The magnitude of ozone changes during the polar night are uncertain because there are no TOMS satellite data during this period as the instrument depends upon reflected sunlight for its measurement. Balloon ozonesonde and SAGE II satellite data indicate that the ozone decrease over Antarctica is mainly confined to an altitude region between about 12 km and 24 km. The ozone concentrations between 15 and 20 km in October of 1987 have decreased by more than 95% from their values two months earlier.

Polar stratospheric clouds (PSCs) form during the winter as the stratospheric air over Antarctica becomes very cold with the long absence of sunlight. The persistence of PSCs, which are thought to play a key role in the formation of the Antarctic ozone hole, has increased since 1984. The 1985 observations showed that for the first time PSCs persisted at 16 km throughout the month of September and into October. Furthermore, PSCs lasted into October 1987 at altitudes as high as 18 km.

Temperatures during August and September in the lower Antarctic stratosphere show little or no change over the 1979-1986 period. However, there is substantial evidence that temperatures during October and November are now colder than in 1979. A decrease of about 8K has occurred near 15 km altitude in November.

From the ground-based observations made at the McMurdo station in 1986 and from the ER-2 and DC-8 aircraft campaign based in Punta Arenas in 1987, the weight of observational evidence very strongly suggests that chemical mechanisms involving man-made chlorine are the primary cause of the rapid decline of ozone during September within the polar vortex. The unique meteorology of the region sets up the special conditions of an isolated air mass (polar vortex) with very cold temperatures that is believed to be required for the unusual chemical mechanisms.

Previous attempts to model the spring-time Antarctic ozone decline solely as a response to changed transport processes required that ozone-poor air be moved into the lower stratosphere from below. Such a movement of air would also require local increases of long-lived trace species of tropospheric origin such as N_2O , CCl_3F (CFC-11), and CCl_2F_2 (CFC-12). Data from instruments aboard the ER-2 aircraft show that these trace species remain relatively constant during September as ozone declines significantly, indicating that it is very unlikely that such a transport mechanism could contribute significantly to the overall decline of ozone within the polar vortex. These data support the hypothesis that a chemical sink for ozone is required within the polar vortex.

The ground-based and aircraft data demonstrated that the chemical composition of the Antarctic stratosphere in springtime is highly perturbed compared to that expected at these latitudes based on measurements at mid-latitudes and predictions using chemical models that predate these new data. The distribution of chlorine among various molecular species is very different from that observed at mid-latitudes, as is the abundance and distribution of nitrogen species. In addition, regions of the polar vortex are severely dehydrated.

The data show, that while the summed abundance of chlorine in all chemical forms within the polar vortex is probably consistent with that expected (about equal to the summed abundance in the rest of the stratosphere), the balance was dramatically shifted from inactive forms of chlorine towards reactive species that might catalytically destroy ozone. The concentration of ClO within the region of very low ozone was enhanced by a factor of 100 to 500 compared with that measured at comparable altitudes at mid-latitudes, reaching about 1 ppbv at altitudes near 18.5 km by the end of September. These measured abundances of ClO appear to be sufficient to account for the destruction of ozone within the region of low ozone if our current understanding of the chlorine catalytic cycle involving ClO and the ClO dimer (Cl_2O_2) is correct. However, there are large uncertainties associated with that understanding and improved laboratory data are needed.

Low abundances of the bromine monoxide radical (BrO) were measured and imply that this species plays a minor role (less than 10%) in the catalytic destruction of ozone at ER-2 flight altitudes.

The stratosphere was both dehydrated and denitrified within the region of low ozone. The low abundances of nitrogen oxides (NO_x) that were measured clearly contradict any theories requiring elevated levels of NO_x .

7.0 POSTSCRIPT

The conclusions of this report regarding global ozone trends would have been aided if the NOAA National Environmental Satellite and Data Information Service (NESDIS) had been able to provide any validated data from the SBUV-2 instrument launched in late 1984. Reliable SBUV-2 data should enable an improved recalibration of the Nimbus 7 SBUV data and provide a system for determining future changes in ozone that does not rely so critically on the long-term stability of the absolute calibration of the Dobson network. There is an urgent need for NOAA NESDIS to increase the priority given for the timely processing and validation of SBUV-2 ozone data if the United States is to have a viable national program for monitoring ozone. Validated SBUV-2 data are absolutely necessary for the international scientific assessment scheduled for 1989 in preparation for the 1990 policy review in accordance with the Montreal Protocol.

The ground-based Dobson, and to a lesser extent the filter ozonometer, measurements play very important roles in a global ozone monitoring system both through direct determinations and as partial ground-truth calibrations for the satellite systems. Continued re-evaluations and corrections of the archived ground-based data by the various national meteorological services are necessary to make the existing 25-30 year records even more useful for trend determinations. The reevaluation will be most effective if the WMO should exercise its traditional role in assisting the implementation of the Global Ozone Observing System by guiding these activities.

NASA must vigorously pursue the new insights into the Nimbus 7-SBUV and TOMS instruments in order to develop the best model of diffuser plate degradation and the associated uncertainties. Once sufficient improvement has been made, the SBUV and TOMS data sets should be reprocessed using the new model of the degradation of the diffuser plate and the data archived for additional scientific studies required by the 1989 international assessment. SAGE II data should be used as an independent measurement of changes in the vertical distribution of ozone to compare with and support this reanalysis.

The re-evaluation and interpretation of both ground-based and satellite ozone data must, in the near future be given higher priority, and involve a broader cross section of the scientific community than in previous years.

8.0 REFERENCES

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9.0 OZONE TRENDS PANEL, REVIEWERS, CHAPTER WORKING GROUPS

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OZONE TRENDS PANEL REPORT

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Appendix 1 - Statistical Approaches to Ozone Trend Detection

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TABLE 1
Coefficients of Multiple
Re-analyzed Dobson Total O
Collected into Bands
 (total percent changes for Measurements
ages
 1969-1986)*
LATITUDE

MONTH	53°-64°N	40°	30°-39°N
JAN	- 8.3±2.2	- 2.0	
FEB	- 6.7±2.8	- 5.0	- 2.2±1.5
MAR	- 4.0±1.4	- 5.0	- 1.2±1.9
APR	- 2.0±1.4	- 2.0	- 3.5±1.9
MAY	- 2.1±1.2		- 1.7±1.3
JUN	+1.1±0.9	- 1.3±1.1	- 1.7±0.9
JUL	+0.0±1.1	- 2.0	- 3.3±1.0
AUG	+0.2±1.2	- 2.0	- 1.3±1.0
SEP	+0.2±1.1	- 2.0	- 1.0±1.0
OCT	- 1.1±1.2	- 1.0	- 1.0±0.9
NOV	+1.5±1.8	- 2.0	- 0.9±0.8
DEC	- 5.8±2.3	- 5.0	- 0.1±0.8
ANNUAL AVERAGE	- 2.3±0.7	- 3.0	- 2.1±1.1
WINTER AVERAGE**	- 6.2±1.5	- 4.0	- 2.3±1.3
SUMMER AVERAGE***	+0.4±0.8	- 2.0	- 1.9±0.8
QBO*	- 2.0±0.6	- 1.0	+1.9±0.6
SOLAR*	+1.8±0.6	+0.8	+0.1±0.6

* per cycle minimum to maximum.

** winter months include December to March, in

*** summer months include June to August, in

report represent one
 or total column ozone
 and errors given in this
 are root of the sum of
 case by 0.2% or less.

+ All uncertainties given in this table and through
 standard error. The total uncertainty in the linear
 (1969 - 1986) can be calculated by combining the
 Table with a systematic error of 0.5% by taking the
 their squares. The uncertainties shown in this Ta

TABLE 2

TOMS TOTAL COLUMN OZONE CHANGES⁺

Latitude Band	Total Change From 11 / 78 - 10 / 85	Total Change From 11 / 78 - 11 / 87
53S - 53N	-2.6 ± 0.5	-2.5 ± 0.6
0 - 53S	-2.6 ± 0.9	-2.9 ± 0.9
0 - 53N	-2.1 ± 1.5	-1.8 ± 1.4
53S - 65S	-9.0 ± 1.8	-10.6 ± 1.6
39S - 53S	-5.0 ± 1.8	-4.9 ± 1.8
29S - 39S	-3.2 ± 2.4	-2.7 ± 2.1
19S - 29S	-2.5 ± 1.9	-2.6 ± 1.5
0 - 19S	-1.1 ± 0.8	-2.1 ± 0.8
0 - 19N	-1.1 ± 1.5	-1.6 ± 1.3
19N - 29N	-3.5 ± 2.2	-3.1 ± 1.9
29N - 39N	-3.7 ± 2.0	-2.5 ± 1.7
39N - 53N	-2.7 ± 1.7	-1.2 ± 1.5
53N - 65N	-2.4 ± 1.6	-1.4 ± 1.4

This analysis represents a linear trend using an autoregressive model through the normalized TOMS data.

+ All uncertainties given in this table represent one standard error.

(C) ANTARCTIC OZONE CHAPTER SUMMARY

I. Ozone Observations

Changes in total column ozone over high southern latitudes in spring-time have been measured by several different techniques from the ground and from satellites. These corroborate one another providing a clear picture of the changes which have taken place. A significant change in the springtime total ozone content over the Antarctic was first reported by the British Antarctic Survey using the Dobson station data at Halley Bay (76 S, 27 W) with a smaller change seen at Argentine Islands (65 S, 64 W) (Farman et al., 1985). The satellite data not only confirm the decrease reported from ground station data but demonstrate that the phenomenon is of large regional scale, at least the size of the Antarctic continent. The key aspects of the Antarctic ozone hole are:

- (1) There is compelling evidence from both ground based and satellite data that the springtime abundance of ozone dropped rapidly after the late 1970's. However, given the high level of interannual variability in Antarctic ozone it is difficult to draw strong quantitative conclusions about the magnitude of ozone decreases during the 1970's.
- (2) The rapid decline in Antarctic total column ozone occurs mainly during the month of September, and low values of ozone persist until the breakdown of the polar vortex in late October or November (see #4).
- (3) The rate of decline of ozone during September appears to be increasing.
- (4) The region of low ozone over Antarctica persisted until late November in 1987, which is the latest since measurements began.
- (5) The total column of ozone was lower in 1987 at all latitudes south of 60 degrees south than any previous year since measurements began. The October monthly zonal mean total ozone amounts at 50, 60, 70, and 80 degrees south were about 8%, 20%, 40%, and 50% lower, respectively, than in 1979.
- (6) While the ozone depletion is largest in the Antarctic spring-time, ozone appears to have decreased since 1979 by 5% or more at all latitudes south of 60 degrees south throughout the year.
- (7) In some instances, total column ozone as measured by the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) instrument changed dramatically (25-50 Dobson Units (DU)) over areas as large as several million square kilometers within a matter of a day or two and these reductions persisted for up to a few days.
- (8) The altitude profiling by balloon-borne ozonesondes show significant ozone layer depletions at a number of stations and are consistent with Stratospheric Aerosol and Gas Experiment (SAGE) satellite ozone profile results.
- (9) Balloon ozonesonde and SAGE satellite data indicate that the ozone decrease over Antarctica is confined to an altitude region between about 12 and 24 km. There is no evidence from the SAGE data of the depletion extending above about 25 km altitude.
- (10) In October of 1987, the ozone concentrations between 15 and 20 km had decreased by more than 95% from their values two months earlier.

2. Polar Stratospheric Cloud Observations

Polar stratospheric clouds (PSCs) form during the winter as the stratospheric air over Antarctica becomes very cold with the long absence of sunlight. The vertical extent of PSCs correlate with cold temperatures. The atmospheric temperatures increase during spring-time starting at higher altitudes resulting in the maximum altitude at which PSCs can exist decreasing with time. Satellite observations of PSCs began in late 1978. The persistence of PSCs which are thought to play a key role in the formation of the "Antarctic ozone hole" has increased since 1984. The 1985 observations show for the first time the occurrence of PSCs at 16 km throughout the month of September and into October. Further, PSCs lasted into October in 1987 at altitudes as high as 18 km.

3. Temperature Observations

Substantial evidence has been presented for a decline in the temperature of the lower stratosphere over Antarctica since 1979 in October and November. The downward trends appear most strongly in the month of October when a substantial decline is observed in the middle as well as the lower stratosphere. During the month of November the trend is confined to the lower stratosphere with maximum negative trend of about 1 K/year centered at about the 100 mb (16 km) level. August and September temperatures show little or no trend over the 1979-1985 period. The October decline appears in both rawinsonde station data and NMC gridded data that include satellite information. This suggests that the ozone depletion has a significant impact on the normal spring radiative warming of the Antarctic stratosphere.

4. Transport Theories for the Antarctic Ozone Hole

The polar lower stratosphere of the Southern Hemisphere is very different from that of the Northern Hemisphere. Strong zonal symmetry of surface conditions in the Southern Hemisphere produces a circulation that is much more symmetric and undisturbed by planetary wave activity than that of the Northern Hemisphere. This leads to conditions in the lower stratosphere in which the lower stratospheric polar vortex is relatively intense, maintaining its integrity throughout the winter season and well into spring. Dynamical modeling suggests that relatively little mixing with air at other latitudes occurs, at least at altitudes where the vortex is sufficiently intense. The air within the polar vortex thus remains very cold and dynamically isolated. When the Sun returns to the South Pole in springtime, temperatures may be near radiative equilibrium. Solar heating might therefore play a more important role in driving the seasonal change there than it does in the Northern Hemisphere, where temperatures are kept well above radiative equilibrium by stronger wave forcing.

The observed Antarctic ozone decline occurs in the lower stratosphere where transport by atmospheric motions has a major influence on the ozone mixing ratio. It is reasonable to suggest that a relatively small climate shift in the Southern Hemisphere could produce a significant change in the total ozone over Antarctica, since the transport of ozone into that region during winter and spring is limited by dynamical constraints associated with the symmetry of the circulation and is very weak in comparison to the almost complete mixing that occurs in the Northern Hemisphere. It is also conceivable that colder temperatures at the beginning of spring produced by weaker wave forcing, or enhanced solar heating in springtime associated with increased aerosols, could lead to transient upwelling during the spring season that would contribute to the springtime ozone decline. But it is very unlikely

that diabatic heating rates would be both sufficiently large and suitably distributed to produce the ozone column reduction observed in 1987.

Evidence from NMC analyses suggests that temperatures in the lower stratosphere over Antarctica have declined over the period 1979-1985 for the months of October and November, and a corresponding decline in the wave driving for September is observed in the same data. Calculations of the radiative temperature change associated with the observed ozone decline suggest that the radiative effect of the ozone decline is comparable in magnitude to the observed trend. The radiative temperature change is largest at the 100 mb level and its vertical structure in the lower stratosphere is very similar to that of the NMC trend for November. During October, a middle stratospheric temperature decline is observed in addition to the lower stratospheric decline. This temperature decline in the middle stratosphere is not expected on the basis of radiation alone, but appears more likely to be associated with decreased wave driving during the previous month. Some combination of altered wave driving and radiative response to ozone changes seems necessary to explain the trend observed in NMC data over the 1979-85 period.

Published attempts to model the springtime Antarctic ozone decline purely as a response to changed transport processes require that low-ozone air be moved into the lower stratosphere from below. Such a movement of air would also require local increases of long-lived trace species of tropospheric origin such as N_2O , CCl_3F (CFC-11) and CCl_2F_2 (CFC-12). Data from the instruments aboard the ER-2 aircraft show that these trace species remain relatively constant at and above the 400°K potential temperature surface (about 15 - 16 km) during September as ozone declines significantly, so that transport of ozone-poor air is unlikely to contribute significantly to the overall decline above this altitude. At lower potential temperatures (i.e. lower altitudes) the ozone decline may be caused by a combination of chemical and meteorological processes. These data support the hypothesis that a chemical sink for ozone is required within the polar vortex. However, the role of radiative and dynamical processes in establishing the conditions necessary for the ozone depletion and in controlling the temperature, cloudiness, and precise degree of isolation of the Antarctic ozone hole must be carefully considered.

5. Chemical Theories and Observations for the Antarctic Ozone Hole

Two distinctly different classes of chemical theories have been proposed to explain the observed loss of springtime Antarctic ozone. The first proposes that the abundance of the oxides of nitrogen are periodically enhanced due to changes in solar activity, while the second proposes that the efficiency of reactions involving chlorine and bromine species are enhanced. Current theories which attempt to describe ozone loss in the Antarctic stratosphere in terms of catalytic chemical destruction involving chlorine or bromine all have the following features:

- (1) conversion of a substantial fraction of the Cl_x contained in the reservoir molecules HCl and $ClONO_2$ into active forms of chlorine such as ClO either by heterogeneous reactions in PSCs or by enhanced OH abundance;
- (2) cycles that effectively catalyze the recombination of O_3 with itself, involving ClO in the rate limiting step with HO_2 , itself, or BrO , forming $HOCl$, the Cl_2O_2 dimer, or Cl and Br , respectively;
- (3) drastic reduction in NO_2 abundance resulting from removal of NO_y as HNO_3 in the condensed phase of PSCs.

Recent laboratory data has shown conclusively that heterogeneous reactions of ClONO_2 (g) and N_2O_5 (g) with H_2O (s) and HCl (s) are rapid enough to play an important role in the chemistry of the Antarctic stratosphere. In particular, HCl was shown to readily diffuse into water ice crystals at low temperatures forming solid solutions. Dissolved HCl in solid solutions was also shown to be very mobile greatly enhancing its reactivity with reactant species on the crystal surfaces. The HNO_3 formed by ClONO_2 reactions with ice and HCl -ice remains in the condensed phase, whereas the chlorinated products desorb into the gas phase.

Our understanding of the chemical composition of the spring-time Antarctic atmosphere increased dramatically during 1986 and 1987. Observations of the vertical distribution and column content of a large number of species, including ozone (O_3), water (H_2O), chlorine monoxide radical (ClO), chlorine dioxide (OClO), chlorine nitrate (ClONO_2), hydrochloric acid (HCl), bromine monoxide radical (BrO), hydrofluoric acid (HF), nitric oxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), total odd nitrogen (NO_x), nitrous oxide (N_2O), methane (CH_4), carbon tetrachloride (CCl_4), methylchloroform (CH_3CCl_3), and CFCs 11 and 12, were made by ground-based observations from McMurdo in 1986 and 1987, and by in-situ and remote sensing techniques from the ER-2 and DC-8 aircraft based in Punta Arenas, Chile in 1987. In addition, the size distribution, abundance, and composition of particles was determined by instrumentation aboard the ER-2; the vertical distribution of aerosols from 12 to 28 km by the DC-8 lidar; and the size distribution from balloon-sondes from McMurdo, in an effort to understand the role of heterogeneous processes. The data clearly demonstrated that the chemical composition of the Antarctic stratosphere in springtime was highly perturbed compared to that expected at these latitudes based on measurements at mid-latitudes and chemical models that predate these new data. The distribution of chlorine species is significantly different from that observed at mid-latitudes, as is the abundance and distribution of nitrogen species. At present it is not clear whether the abundance of total inorganic chlorine (the summed abundance of chlorine in all chemical forms) is perturbed relative to that expected, or just the partitioning. In addition, it was observed that the amount of total water within the chemically perturbed region of the vortex was significantly lower than that at the same potential temperatures immediately outside it.

Based on the observations made at McMurdo and from the aircraft campaign the weight of observational evidence strongly suggests that chemical mechanisms involving man-made chlorine are primarily responsible for the observed decrease in ozone within the polar vortex at potential temperatures greater than 400°K. It is clear that meteorology sets up the special conditions of an isolated air mass (polar vortex) with very cold temperatures required for the perturbed chemistry. It is also clear from the 1987 ER-2 flights that the region of dehydrated and denitrified air maintained a sharply defined latitude gradient throughout most of the campaign. The meteorological flow must therefore have been such as to maintain a kind of "restraint vessel", in which the perturbed chemistry could proceed without being influenced by mixing in more nonnal stratospheric air from outside or below. The concept of mixing at the region of sharp latitudinal gradient is important, since it has the potential to supply nitrogen oxides which would tend to decelerate the chlorine chemistry. The meteorology is thus important in the termination phase as well as in the initiation phase.

As stated earlier there is strong evidence that the chemical composition of the springtime Antarctic stratosphere is highly perturbed compared to midlatitudes. The data shows that while the abundance of total chlorine is probably consistent with that expected, the

partitioning of Cl_x was highly perturbed compared with that observed at mid-latitudes and expected at high latitudes. The concentrations of HCl were low, whereas the concentrations of OCIO and ClO were significantly elevated. Somewhat elevated concentrations of ClONO_2 were also observed. This is clear evidence that the balance was dramatically shifted from inactive forms of chlorine towards reactive species that can catalytically destroy ozone. In-situ ER-2 and ground based measurements of ClO showed that its abundance within the chemically perturbed region of the Antarctic atmosphere is a factor of 100 to 500 greater than that measured at comparable altitudes at midlatitudes, reaching a maximum value of about 1 ppbv near local noon at approximately 18.5 km altitude. The in-situ aircraft data demonstrated that within the chemically perturbed region of the vortex near 18.5 km the abundance of ClO during September of 1987 was sufficient to account for the destruction of ozone if our current understanding of the chlorine-ozone ClO dimer catalytic cycle is correct. The rate of decrease in ozone during the month of September at the highest altitudes at which the ER-2 was operated was consistent with simultaneously observed concentrations of ClO . Another line of observational evidence consistent with ozone destruction by chlorine catalysis is that during the month of August, there was no strong positive, large scale correlation between ClO and O_3 observed, whereas by the middle of September, as the ozone concentration was dropping at ER-2 altitudes, a strong anti-correlation developed on the larger spatial scales.

The bromine monoxide radical was observed at abundances of a few pptv within the chemically perturbed region of the vortex at the flight levels of the ER-2. The abundance of BrO decreased at lower altitudes. Total column measurements of BrO from the DC-8 and from McMurdo in 1987 are currently being analyzed. The low measured abundances of BrO mean that the catalytic cycle involving the $\text{BrO} + \text{ClO} \rightarrow \text{Br} + \text{Cl} + \text{O}_2$ reaction is not the dominant catalytic mechanism for ozone destruction, but never the less probably accounts for 5 - 10% of the ozone destruction at the ER-2 flight levels.

The in-situ ER-2 observations of the abundance of odd nitrogen, which is the sum of all nitrogen-containing reservoir and radical species, show, like total water, very low values within the chemically perturbed region of the vortex, indicating that the atmosphere has been denitrified, as well as dehydrated. Abundances of gas phase NO_y of 8-12 ppbv were observed outside the chemically perturbed region, while abundances of 0.5 to 4 ppbv were observed inside the chemically perturbed region. In addition, some of the NO_y observations suggest that NO_y component species are incorporated into polar stratospheric cloud (PSC) particles, and nitrate was observed in the particle phase on some of the filter samples and on some of the wire impactor samples taken in the chemically perturbed region of the vortex. The ground-based and aircraft column measurements of nitric oxide, nitrogen dioxide, and nitric acid exhibit a strong decrease in the abundance of these species towards the center of the vortex. These low values of nitrogen species are contrary to all theories requiring elevated levels of nitrogen oxides, such as the the proposed solar cycle theory.

Observational data that air within the chemically perturbed region of the vortex is dehydrated and that the NO_y abundances are very low are consistent with theories that have been invoked whereby the chlorine reservoir species, ClONO_2 and HCl , can react on the surfaces of polar stratospheric clouds to enhance the abundance of active chlorine species, i.e. ClO . The observations also support the picture that the abundance of NO_y is low because odd nitrogen can be removed from the atmosphere by being tied up in ice crystals, which can then gravitationally settle to much lower altitudes. Low abundances of NO_y are needed to prevent the rapid reconversion of ClO to ClONO_2 .

6. Global Implications

Besides its dramatic character and its sudden appearance, a reason for concern about the "ozone hole" is that the processes, which appear to play a decisive role in the polar environment and which are not fully understood or included in atmospheric models, could be important at other latitudes and contribute to a global ozone depletion. There are two observations discussed in this Ozone Trends Report that suggest that there is an urgent need for additional research:

- (a) there is evidence of ozone depletions in winter at mid and high latitudes in the northern hemisphere that are larger than calculated using photochemical models, and
- (b) while the column ozone depletion is largest in the Antarctic spring-time, ozone appears to have decreased since 1979 by more than 5% at all latitudes south of 60S throughout the year.

There are two processes currently not included in photochemical models that might provide explanations for these two observations: (1) the observation of winter-time ozone decreases in the northern hemisphere might be explained by heterogeneous chemical processes, while: (2) the observation of year-round decreases in ozone outside of the polar vortex in the southern hemisphere might be explained by a "dilution effect" from the spring-time Antarctic ozone hole.

(1) Since aerosols are present in the stratosphere at all latitudes, it is important to understand if heterogeneous processes similar to those that are important in Antarctica could occur at other latitudes and possibly lead to ozone destruction in other regions of the atmosphere. At present the importance of heterogeneous processes at other latitudes is unknown. However, it is clear that even though there are significant differences in the meteorology of the Arctic and Antarctic, PSCs are formed in the Arctic and might play an important role in controlling ozone. Arctic temperatures at 70 mb reached -87°C in early February 1984, probably sufficient to cause dehydration. An intensive field measurement campaign similar to that used to investigate the Antarctic ozone hole is required.

It should be noted that both the abundance and catalytic efficiency of the liquid sulfuric acid aerosol particles in the global Junge layer are lower than the PSCs over Antarctica. However, some heterogeneous processes might periodically become important and lead to ozone destruction after large volcanic eruptions, when the amount of particles in the stratosphere is enhanced by several orders of magnitude. If heterogeneous processes are important at mid-latitudes then the concentrations of ClO should be elevated in the Junge layer as they were over Antarctica. Measurements of the vertical distribution of the ClO radical at mid-latitudes in the northern hemisphere from balloon (24-40 km) and aircraft platforms (15-20 km) show that the abundance of ClO in the peak region of the aerosol layer, i.e. 16-20 km, is not significantly elevated as in the chemically perturbed region of the Antarctic ozone hole. This indicates that conversion of inactive reservoir forms of inorganic chlorine, i.e. HCl and ClNO_3 , to the active form, i.e. ClO, does not appear to be detectably enhanced (less than a factor of 3 to 5) in this region of the stratosphere.

(2) The possibility of a "dilution effect" of the polar anomaly observed in spring over Antarctica must be considered as another possible global (or least southern hemisphere) implication of the Antarctic ozone hole. Since the chemical lifetime of ozone in the lower stratosphere is of the order of a year, air masses, with depleted ozone amounts, move toward the equator as soon as the winter vortex ceases to exist (November and December). As volumes of air with extremely low ozone are transported toward lower latitudes every year, the effects might partly accumulate and a limited change in the total hemispheric ozone content could become noticeable. At present this issue is being addressed using both multi-dimensional theoretical models and the TOMS satellite data by examining changes in total column ozone in both hemispheres.

7. References

- Farman, J. C., B. G. Gardiner, and J. D. Shanklin, Large losses of total ozone in Antarctica reveal seasonal $\text{ClO}_x\text{-NO}_x$ interaction, *Nature*, 33, 207-210, 1985.

(D) THEORETICAL PREDICTIONS

The concern over changes to the global environment, in particular to stratospheric ozone, has spurred the development of stratospheric models. Atmospheric chemistry and transport are combined in current models and used to make predictions of the changes in ozone that may be expected over the next century. Modeling the global ozone distribution requires chemical transport models for tropospheric as well as stratospheric ozone and other trace gases, but emphasis on model development has been placed on stratospheric chemistry and circulation. These models take into account the increasing concentrations of source gases, such as CH₄, N₂O and chlorofluorocarbons (CFCs), and calculate the chemical changes in the stratosphere. All models predict the direct photochemical effects, and a few models now examine perturbations to stratospheric temperatures and circulation and their feedback on ozone. The models used in these assessment studies do NOT include the unusual chemistry associated with polar stratospheric clouds that is now believed to be part of the Antarctic ozone "hole". Therefore, neither predictions of the hole, past and future, nor the global or hemispheric significance of Antarctic chemistry, are included in this assessment.

The conclusions from the Ozone Trends Report indicate that depletions in column ozone since 1969 at northern mid-latitudes appear to be much greater than predicted. Those predictions involved some of the same 2-D models that are used in this assessment. If the discrepancy between models and observations over the past 20 years is significant, then a major question arises as to what uncertainties should be placed on our current predictions for the next 100 years. Potential causes of the larger than predicted decrease in column ozone center on the lower stratosphere since calculated changes to ozone concentrations in the upper stratosphere are consistent with observations. Of the many possible sources of error in the Ozone Trends Report simulations, three may be singled out: (1) errors in the standard gas-phase chemistry involving chlorine in the lower stratosphere; (2) failure to include a heterogeneous chemistry in the northern hemisphere that is similar to, but different from, that occurring over Antarctica; (3) a small long-term trend in lower stratospheric circulation and temperatures. Points (1) and (2) can be addressed directly by a vigorous research program involving theoretical modelling, laboratory studies and, especially, aircraft expeditions to measure the photochemistry of the lower Arctic stratosphere. Such a measurement campaign would be similar to the Antarctic campaign of September 1987, which was led by NASA, involving NOAA, universities and international cooperation. If the unexplained part of the recent decline is associated with point (3), climate change, then it would have been difficult to detect over the last 20 years. Hence, we must work on the feedback of climate change on ozone perturbations.

Key Findings

(a) Growth in trace gases other than chlorinated species is expected to have major impact on stratospheric ozone. An increase in CH₄ reduces the rate of chlorine-catalytic destruction of ozone and also generates ozone in the lower stratosphere and troposphere. Growth in CO₂ reduces stratospheric temperatures which lead in turn to increases in ozone. The solar cycle is also predicted and observed to influence column ozone (see Ozone Trends Report, section B); its variations were not included in these predictions.

(b) Current predictions of future changes in global ozone are not significantly different from the previous assessment (WMO, 1985). Changes in the chemical kinetic and atmospheric models have not altered the basic predictions.

(c) Two-dimensional models were used to perform (1) a traditional steady-state calculation for an atmospheric composition expected by the middle of the next century and (2) a time-dependent scenario, calculating year-to-year changes in composition and ozone. Both simulations result in similar predictions.

(d) The expected decline in column ozone over the next 30 years should be moderate over the tropics, -0.5 to -1 %, and largest at high latitudes during late winter and early spring, -2 to -3 %.

(e) Large global depletions in ozone concentrations near 40 km altitude are a consistent result across all models and all scenarios, and changes should exceed -15 % at mid-latitudes during the first-half of the 21st century.

(f) Several models shown here have included feedbacks between the predicted ozone change and the transport of trace gases. Differences are apparent among these models, especially at high latitudes, and we emphasize that predicting changes in stratospheric circulation and temperatures is still a research topic.

(g) The current assessment models do not adequately simulate the chemistry believed to be responsible for the Antarctic ozone hole. Thus, they cannot answer critical questions such as whether the Antarctic ozone hole will spread over the southern hemisphere or whether the unusual chemistry associated with the Antarctic hole will appear in the Arctic.

(E) SUMMARY

Since the Montreal protocol was negotiated there have been several changes in our understanding of the extent of trends in atmospheric ozone and of the cause of the observed trends. The major differences are:

- (1) The large reported trends in atmospheric ozone since late 1978 that were based on satellite data alone are an artifact.
- (2) There are measurable decreases in total column ozone since 1969 that cannot be ascribed to any known natural phenomena. These decreases were not previously recognized.
- (3) The observed ozone changes since 1969 in the northern hemisphere are greater than predicted; the cause of this discrepancy is not known.
- (4) The observed changes in ozone since 1969 may be due wholly, or in part, to the increased atmospheric concentrations of trace gases, primarily the CFCs.
- (5) The weight of evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in Antarctic ozone in springtime within the polar vortex.

30 March 1988

Testimony Given by:
Professor Sayed Z. El-Sayed

Texas A&M University
College Station, TX 77843

In regard to:
Effect of Ozone Depletion on Antarctic Marine Ecosystem

My name is Sayed Z. El-Sayed. I am a Professor of Biological Oceanography at Texas A&M University. I have been a member of the faculty of the Department of Oceanography at Texas A&M since 1960. My area of specialty is the study of the productivity of the sea. I've conducted research in the Gulf of Mexico, the Mediterranean Sea, the Atlantic, Pacific, and Indian Oceans. My involvement in the study of the productivity of the Southern Ocean dates back to the early '60s. For the most part, my research in the Antarctic has been supported by grants from the Division of Polar Programs, National Science Foundation, and through contracts with the National Oceanic and Atmospheric Administration (NOAA).

The research activities that I will be discussing today have been supported by the National Science Foundation. The views expressed are solely my own and do not necessarily reflect those of the funding agency.

Ozone depletion over Antarctica is now causing concern about the consequences of increased level of ultraviolet (UV) radiation (in particular UV-B) on life in the Southern Ocean. One area of concern involves the phytoplankton, the microscopic algal cells which constitute the base of the food web in aquatic ecosystems. Although the effects of UV radiation on marine phytoplankton in temperate and subtropical regions had been studied by several investigators, no such studies had

been carried out on Antarctic phytoplankton.

Since I have been involved in the study of the productivity of Antarctic phytoplankton for more than 25 years, naturally I was interested in the study of the effect of increased UV radiation (as a result of ozone depletion) on the productivity of Antarctic phytoplankton.

Thus, with funds and logistical support provided by the Division of Polar Programs, NSF, a small group composed of three Texas A&M graduate students and me embarked in early November 1987 on an in-depth study of the effect of UV on Antarctic marine phytoplankton. The field experiments, which lasted between 6 November and 8 December, 1987, were carried out at the U.S. base at Palmer Station, Anvers Island, Antarctica.

— The investigation had as its main objective the study of the effects of UV in primary production, pigment composition and species composition of phytoplankton in Arthur Harbor, Antarctica. We had originally planned to conduct our experiments on the phytoplankton of the open waters of Arthur Harbor. Unfortunately, however, due to the heavy sea-ice conditions that covered all, or almost all, of Arthur Harbor during the entire period of investigation, we were forced to modify our sampling strategy and to depend, for the most part, on the water pumped from an ice-hole (sea-ice thickness was 4-5 feet) to the experimental site. Additionally, we collected samples of brown melt-ice in the vicinity of Palmer Station's ship dock, as well as water samples from the nearby open waters at Bonaparte Point.

The response of the phytoplankton communities to varying levels of UV radiation was studied using a specially designed array of tanks

and chambers (three replicate chambers in each tank). In an effort to simulate as natural conditions as possible, the treatment tanks were made of either transmitting or absorbing plexiglas (depending on whether the object was to eliminate, reduce, or enhance UV level). The tanks were subjected to four kinds of irradiation treatments: (a) ambient, including natural UV light; (b) ambient level, excluding both UV-A (320-380 nanometers, nm) and UV-B (290-320 nm); (c) ambient with reduced levels of UV-B; and (d) ambient with enhanced level of UV (enhanced by about 6.5% above ambient).

The three phytoplankton parameters which were the focus of this study are: (a) primary production, i.e., the production of organic matter through the process of photosynthesis, (b) phytoplankton pigments, and (c) composition of the algal cells.

RESULTS

It should be pointed out that the analysis of the data collected at Palmer Station during the 5-week investigation is still underway. Here we summarize some of the preliminary results of our field experiments.

(1) Primary Production

The highest primary production rates were measured in the samples incubated in the tank where both UV-A and UV-B were excluded. By contrast, photosynthetic rates were lowest in the tank with enhanced UV-B.

(2) Phytoplankton Pigments

Of the plant pigments studied, chlorophyll a is the most important. Its concentration is usually taken as an indicator of the phytoplankton biomass.

In the short-term (i.e., 4 hr) experiments, we did not detect significant differences in chlorophyll a concentration in the tanks exposed to the varying doses of UV. However, long-term (i.e., 24-48 hr) exposure to UV radiation produced drastic changes in phytoplankton pigmentation. After a 48 hr incubation period, the highest and lowest pigment concentrations were measured under "no UV" and "enhanced UV" conditions, respectively. On the other hand, intermediate pigment concentrations were observed in the "ambient UV" and "reduced UV" treatment tanks.

(3) Algal Composition

Study of the composition of the algal cells which have accumulated at the bottom of the tanks (towards the end of the experiments) showed marked differences in their biomass and in the relative abundance (i.e., survival rates) of the algal groups (phytoplankton community is a melange of diatoms, dinoflagellates, silicoflagellates, and other organisms). Those collected in the tank where UV-A and UV-B were excluded, the biomass was largest and appeared bright golden in color. In vivid contrast, little algal material was present under UV-enhanced conditions. Microscopic examination of the cells (exposed to enhanced UV radiation) gave the appearance of being bleached. Moreover, the greater relative abundance of empty diatom frustules (shells) seems to point to the deleterious effects of enhanced UV radiation.

Significance of the Palmer Station Findings

The results of the 5-week study carried out at Palmer Station in November/December 1987 clearly point to the harmful effect of enhanced UV radiation on the productivity of Antarctic phytoplankton. Further, study of the species composition of the phytoplankton in the four experimental tanks indicate that several species are more sensitive to UV-radiation than others. Indications are that the small-sized cells (nanoplankton), on which the myriads of developmental stages of zooplankton (including krill) and fish larvae depend for survival, are more sensitive to increased UV radiation than the large-sized diatoms.

Since the phytoplankton constitute the basic primary producers in the Southern Ocean, on which all the other components of the ecosystem (namely, zooplankton, krill, fish, winged birds, penguins, squid, seals, and whales) depend for their sustenance, any substantial decrease in the primary production, or any significant shift in the species composition of the phytoplankton, will have serious ecological reverberations throughout the entire Antarctic marine ecosystem.

Cautionary Note!

One needs to emphasize again the preliminary nature of the results of this investigation. Further, considerable caution should be exercised in applying the results of these laboratory experiments to the "real world" - the Southern Ocean. Since the depletion of the ozone levels will be with us for the next fifty or hundred years, it is imperative that efforts should be made to intensify and expand the research efforts, not only on phytoplankton populations, but also on all other components of the Antarctic food web. Only then can an in-depth assessment be made of the effects of enhanced UV levels on the Antarctic marine ecosystem.

STATEMENT

ELWOOD P. BLANCHARD
EXECUTIVE VICE PRESIDENT
OF

E. I. DU PONT DE NEMOURS AND COMPANY

TO

SENATE ENVIRONMENT AND PUBLIC WORKS COMMITTEE
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION

MARCH 30, 1988

Mr. Chairman, members of the Subcommittee, my name is Elwood Blanchard. I am an Executive Vice President, of the Du Pont Company. I am appearing before the Subcommittee to provide my Company's views on the matters raised in your letter of March 24, 1988.

Last year, we testified that the science did not reflect a need to reduce global CFC emissions but that we did believe global emission controls were needed. This was then and it remains today a global issue. We strongly supported adoption of the Montreal Protocol including the scheduled reductions and believe that our efforts assisted the U. S. in achieving acceptance of this landmark agreement by over 30 countries.

On March 15, the Ozone Trends Panel announced new scientific findings that indicate there has been depletion of the global ozone layer including what has come to be called the Antarctic Hole. They also indicated that chlorine from CFCs in some way appears to play a role in these effects.

I am not here to debate whether or not this science is correct or how much certainty we can place on it. I am appearing today to discuss our actions based on these new findings.

We understand that there will continue to be substantial uncertainties surrounding the atmospheric science that was interpreted by the experts and released on March 15. However, we believe that this was a carefully conducted review of existing data and the findings should be seriously considered.

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Du Pont reviewed this scientific information as soon as it became available to us and quickly established as a goal for Du Pont the orderly phase out of production of fully halogenated CFCs.

We believe that the replacement of fully halogenated CFCs should be viewed as an opportunity, not only for the current CFC manufacturers, but also for those with technology and ideas for solutions that are totally different from ones we have under investigation. We do not presume to have all the answers as to how the world should deal with these new findings. With the changing market parameters attendant with CFC phaseout, heretofore uneconomic technologies may be developed.

We have committed to phase out production. We do not believe that precipitous action is called for and we propose to conduct our phase out in an orderly fashion. We pledge to work closely with our customers and suppliers to provide as much lead time as possible during this transition.

Du Pont revitalized its earlier program to develop alternatives to the fully halogenated CFCs in 1986 when we concluded that emissions should be controlled. We are continuing this program, but we cannot guarantee that it will be successful. We have identified a small number of chemicals discussed below which appear to have the necessary properties to substitute for some important uses of CFCs. However, many uncertainties remain. We still need to develop adequate information that will assure us that they can be made and used safely. We continue our work to develop technology to produce these compounds. It is not clear to us that we have identified the best route of manufacture or that it will be commercially viable. In addition, we expect that we will have to invest hundreds of millions of dollars to erect production facilities. It is still too early to determine if this investment will be financially viable.

As indicated earlier, we believe that this issue is global and the solution must be global. We hope that our action stimulates other producers and users to adopt the same goal and work toward an orderly phase out.

We are firmly convinced that the most effective action to address this challenge is the early ratification of the Montreal Protocol by as many of the countries of the world as possible. We also believe that the member states should then be convened as soon thereafter as possible to review the scientific findings and to establish appropriate global responses to these findings.

We encourage you to use your good offices in support of the U.S. efforts to achieve early ratification of the Protocol

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and following this to support the prompt review of the science to consider further global limitations.

You also asked that we address steps Du Pont is taking to develop substitutes to fully halogenated chlorofluorocarbons; the timetable to develop those substitutes and, last, we were asked to include production data for fully halogenated CFCs for 1980 through 1988.

STEPS TO DEVELOP SUBSTITUTES

Identification

The story of the development of alternatives is one that started about a decade ago with a review of the basic physical properties that were required to accomplish the jobs that CFCs performed in each of their applications. The challenge to the team that conducted the initial work then became the identification of one or more materials that, at least theoretically, possessed the physical properties needed in each end use application.

This activity continued into the early eighties and identified thirteen potential candidates.

Three of these candidates, HCFC 22, HCFC 142b and HFC 152a, are commercially produced. HCFC 22 is a major product in the worldwide market, with applications in refrigeration and air conditioning. It also is used widely (with no atmospheric

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release) as an ingredient in the production of fluoropolymers. Opportunities may exist for expansion of its uses to include substitution for CFC-12 in some blowing agent applications and more broadly as a refrigerant in stationary refrigeration systems and in mobile air conditioners. However, extensive equipment redesign would be required for the latter applications.

Fluorocarbons 142b and 152a are now manufactured in limited quantities, primarily for consumption in fluoropolymer production. Both have desirable thermodynamic properties, but suffer the disadvantage of being flammable. Also, product cost is significantly higher than that of the major current products.

In addition, based on preliminary toxicologic testing, four of the remaining ten candidates, HCFC 21, HCFC 31, HCFC 132b and HCFC 133a, have been disqualified by Du Pont from serious commercial consideration for toxicologic reasons. The information that HCFC 132b causes testicular damage in rats was not discovered until mid-1987.

Of the remaining six candidates, HCFC 123, HFC 134a and HCFC 141b appear to be leading candidates for the major uses of CFC 11 and CFC 12. Although we have recently introduced a

product with 25% less ozone depletion potential for some of the solvent uses of CFC 113, no single compound or group of compounds appear to possess the combination of properties needed to qualify as a substitute for CFC 113.

Once the compounds were identified and have passed the preliminary toxicology screens, a number of additional evaluations and data need to be considered. The materials must be capable of being produced on a commercial scale at a cost that society is willing to pay. The materials must pass our rigorous toxicity testing, since they will be so widely distributed throughout our society and will be produced in such large quantities.

Process Development

Another component in our evaluation process is an assessment of the ability of the candidate to be produced in commercial quantities at a price society is willing to pay. In 1986, when we concluded that it was necessary to control the growth in emissions of fully halogenated CFCs and announced our decision to our customers and the public, we revitalized and intensified our effort to devise practical methods for the production of these substitutes. Our work has identified potential commercial routes to HFC 134a, HCFC 123 and HCFC 141b. We have or soon will initiate pilot scale manufacture of these compounds. Our goal is to produce sufficient material to satisfy the needs of the toxicity tests, and also to have sufficient quantities available to permit needed end use evaluations to be conducted during the time we develop a commercial scale process.

Facilities Planning

We have established a team to determine whether our existing facilities can be used to produce the candidate substitutes or whether new plant construction will be needed. A preliminary assessment indicates that new facilities will be needed. The first consideration is that we will need to accommodate transition to substitutes. If we are successful, the substitutes will be employed in new equipment while existing equipment will still be required for the existing products. Thus, until air conditioning, refrigeration and other equipment that relies on CFCs becomes obsolete or until such equipment is otherwise replaced or retrofitted to use the substitute compounds, the nation will continue to need supplies of the existing products. For some period, we will continue to supply a part of this need.

I would like to digress briefly to discuss just one application of CFCs and its impact on the country and the economy. Approximately 40% of the U.S. consumption of fully halogenated CFCs is used in the area of refrigeration and air conditioning. Over three-fourths of this is used to service equipment like home refrigerators, food store display cases,

mobile (auto) air conditioners and office air conditioning. This equipment can not operate with other refrigerants. Therefore, if a total immediate cessation of CFC manufacture occurred, all of this equipment would be made obsolete. An analysis of the value of these uses was recently made by the Alliance for responsible CFC policy and is attached as Attachment A.

For the home refrigerator, any attempt to use other refrigerant gases, such as more toxic ammonia or SO₂, would be worse than trying to run a car on diesel fuel. The retrofit to accommodate the substitute compounds could be compared to changing a car from one which burns gasoline to one which burns diesel fuel. Not only does the engine have to be redesigned and changed but also ancillary equipment, such as the fuel supply system would need to be changed, the exhaust system would have to be changed, etc. For substitutes such as 134a (where no proven refrigerant oil is known), the compressor would need to be changed along with some ancillary equipment. Preliminary estimates are that such modifications would require several hundreds of dollars or more of expense, once the retrofitted parts have been designed and tested.

This analogy applies not only to the home refrigerator, but to commercial application of refrigeration. If we look at the food distribution chain, we see that food products are shipped in approximately 180,000 refrigerated cars and 27,000 freight cars. These food products are delivered to more than 40,000 supermarkets and about 180,000 other food stores. If fully halogenated CFCs were not available to service this existing equipment, food could not be delivered to distant markets in unspoiled condition. This would mean a reduction in the available supply of foodstuffs and an increase in the price of fresh food due to increased wastage. This does not consider the impact of the reduced availability of convenience foods, due to the reduced availability of refrigeration and freezing capacity.

Therefore, unless the nation plans carefully for this transition, we could be faced with significant commercial and societal disruptions, because this same story could be repeated with respect to many of the applications for CFCs that affect our daily lives. A successful transition to substitutes for the fully halogenated CFCs will require the dedication, cooperation and hard work of government, industry and the public. We must begin, as has Du Pont, with materials, such as HCFC 22, that are already available and find more ways to utilize them. We must also heighten conservation efforts to prevent the unnecessary release of CFCs. For example, we should all seek to encourage efforts such as those which reduced emissions in the cleaning agent industry. In support of these efforts, we published, in 1987, information describing appropriate conservation methods to be used by the trade. We also have announced using HCFC 22 as a test for halons and in some foam blowing applications.

In addition to our search for new substances, we have also investigated the possibility that blends or azeotropes of existing commercial products could be used at least on an interim basis to reduce ozone depletion potential. We have introduced FREON SMT as a new azeotrope of CFC 113, methanol and dichloroethylene which has reduced ozone depletion potential.

With regard to this approach, blends or azeotropes of CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115 with low depletion potential commercial products such as CFC-22, HCFC-142b and HCF-152a are being studied. Mixtures or azeotropes would not eliminate the contribution of chlorine to the stratosphere, but could have significant impact as an interim measure if they were usable in existing equipment. The full range of combinations which could be used to reduce ozone depletion potential for the major industry segments is being explored. However, to date, we have not done enough evaluation to commit to any new candidate blends or azeotropes for commercialization. These preliminary evaluations are expected to be completed within about a year. If promising candidates are identified, small quantities will be made available shortly thereafter from existing commercial facilities. We estimate the time it would take to have the material in commercial production and qualified by customers for use in their operations would be 2 to 3 years or longer.

Development of Safety Information

Since the CFCs are so widely distributed in commerce and literally touch the lives of each one of us daily, we and the other producers who are interested in the development of the substitute materials HCFC 123 and HFC 134a consider it only prudent to insure that these substitutes are safe for their intended uses. To this end, fourteen producers, including Du Pont, have joined forces to conduct the needed tests. To avoid needless testing, a panel of industrial toxicologists have developed a test schedule which calls for a battery of preliminary tests to be conducted simultaneously. This will lay the foundation for more extensive testing and will accomplish two things. First, it will update previously conducted testing to confirm the low toxicity of these compounds and will add additional test data to the dossier on these compounds. Second, since the preliminary tests like the Ames and other mutagenicity tests use only small quantities of compound, these tests can be conducted using supplies from research sized reactors while larger facilities are being installed to supply the needs of long-term tests.

The parties to the testing program believe that it is important to begin all testing as soon as possible. Although an ambitious schedule has been established, the test programs are not expected to be completed for about five years. This test schedule is ambitious and will be accomplished in a shorter time than are typical toxicity testing programs.

TIMETABLE

You have also asked about our timetable for developing substitutes for fully halogenated CFCs. I have touched briefly on this in discussing the history of the identification of the most likely candidates as substitutes. We do not have a specific date in mind for the introduction of substitutes other than to say that it should be as prompt as possible and it should be done in an orderly fashion so as to avoid disruption of our economy. As you know, we called for limitations on CFC emissions in 1986 as a precautionary measure based on the growth of CFC usage and on the projections of the future impact of that growth. It was during this period that we revitalized our effort to develop substitutes for the fully halogenated CFCs. As you also know, one of our prime candidates, HCFC 132b, was dropped from further consideration by us in 1987 as a result of preliminary observations in a long-term inhalation study. This was a blow to our substitutes program because this HCFC was the leading candidate to use as a replacement for CFC 113 in many solvent applications.

With regard to the remaining leading candidates, we have undertaken process development work and expect that this work will be completed by 1990. We have also undertaken preliminary design work and expect that this work will be completed between 1990 and 1991. If the process development and design phases of our program are successful, we do not expect to commit capital or begin the construction phase of our work until 1990. Since we are compressing these construction related activities, construction could be delayed if we cannot complete design and specifications for long lead time items of process equipment. It is also possible that we could be delayed by the permitting demands of the Air, Water and Waste laws. Until we are further downstream with process development work, it will be difficult to assess what permits will be required and when data will be needed in support of the permit applications. In addition, the requests for capital for these programs will be competing with the other capital demands of the Company. Such capital will be forthcoming only if these projects compare favorably with other demands for capital.

As indicated in the discussion of the process and design work, we will need to make an investment decision prior to the time all of the toxicology data is in hand. We will rely on the preliminary data, as will our customers in determining whether the identified substitutes are viable commercial candidates. If the preliminary data is encouraging, we may be able to commit the funds in 1990 that will enable us to start production in late 1992. However, if the preliminary information is not encouraging, we may need to wait until about 1996 before start of manufacture.

To enable our customers to be able to use these compounds once they are commercially available, we have provided

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a number of samples to customers conducting applications research. We have small quantities of HCFC 123 available from an existing commercial process and we have recently begun to supply samples of HFC 134a from a small lots facility. We have seen significant interest by the user industries to work with us in the development of equipment that will use the substitutes. We are also sure that there will be efforts to seek to retrofit existing equipment if supplies of existing products fall below levels needed.

PRODUCTION 1980 THROUGH 1988

The data for U.S. production for the fully halogenated CFCs from 1980 through 1986 is presented in Attachment B. Also presented in this attachment is an estimate of the 1987 U.S. production for the fully halogenated CFCs.

I thank you for your attention and will be pleased to answer any questions you may have concerning these matters.

test330 gah/28

ECONOMIC ANALYSIS

Introduction

CFCs have played an important role in many of the social, demographic, and technological changes and advancements that have occurred in the United States over the last 50 years. These compounds are very much a contributor to a high-tech economy.

Developments such as the demographic growth in the Sun Belt, an increasingly mobile population, construction of vast indoor office, retail and recreational complexes, were made possible because of the availability of relatively inexpensive climate conditioning technology made possible by CFCs. The era of computerization, and the rapid miniaturization of electronic parts, was greatly enhanced by the cleaning capabilities of CFC solvents. Additional examples are too numerous to list.

Unilateral action to control CFCs in the United States would have a significant negative impact on many key U.S. industries, industries that contribute to the quality of life in the United States and enhance our position in the global economy. Many developing nations are desirous of having the technologies that CFCs make possible, and many of our global competitors are anxious to provide these technologies to these countries and everywhere else.

The United States initiated unilateral action on CFCs in the late 1970's, singling out specific uses (aerosols), that received little support from other major CFC users around the world. A better solution was needed, one that addressed the environmental need and recognized the economic facts and produced an economic stimulus to receive that environmental need.

The Montreal Protocol attempts to strike this balance. The following material provides the reader with an understanding of the widespread use of CFCs in our society. The economic analysis, prepared by Putnam, Hayes and Bartlett, Inc. of Washington, D.C., summarizes the expected costs of the Montreal Protocol to the U.S. economy, points out how effective the agreement will be in stimulating the development of new CFCs and CFC-utilizing technologies, and shows that any attempts to accelerate the Protocol's control measures, while providing little or no additional environmental benefit, would significantly increase the costs to U.S. citizens.

CFC Uses in the United States

By any measurement, CFCs are important to modern life:

- They help us meet basic needs—food, shelter, health care, communications, leisure, transportation.
- They contribute immeasurably to our comfort, safety and productivity.
- In the United States alone, CFCs are used by some 5,000 businesses at nearly 375,000 locations to produce goods and services worth more than \$28 billion a year. CFC-related jobs total 715,000. The estimated value of installed products relying on CFCs is more than \$135 billion.

Major CFC applications are described here, beginning with the one that started it all: refrigeration.



Refrigeration

\$6 billion*

\$2,000 jobs**

The first commercial CFC was compounded in 1931, the result of an intensive research effort by a refrigerator manufacturer (General Motors) to find an efficient, safe refrigerant for home use. Ammonia, sulfur dioxide and other refrigerants then in use were considered toxic or presented other hazards.

The new compound revolutionized the industry.

The first refrigerant, ice, served well for its time. It kept foods cool so they would last longer, and ice railroad cars made possible the shipment of perishables from distant points. But ice melts and has to be replaced, and that pain under the icebox always seemed to need emptying.

Early chemical refrigerants eliminated these drawbacks and performed the cooling job more efficiently, but their toxicity was an ever-present hazard. Also, some were explosive and/or flammable and most were corrosive.

*Value of products/services, per year.

**Direct CFC-related industry employment. Refrigeration and air conditioning servicing adds \$1.5 billion in value and 473,000 jobs.

CFCs captured the home refrigeration market because they are efficient, safe, stable and cost-effective. Another advantage is that they are chemically inert, so they do not damage gaskets, seals or lubricating oils in the refrigeration system. Today 75 percent of the food we eat depends upon the use of CFC refrigerants at some point in the production and distribution chain. In fact, many foods we enjoy would not be available in stores or would cost much more were it not for refrigeration.

Because of their unsurpassed cooling efficiency, CFCs are also widely used in commercial and industrial refrigeration and freezing equipment. Today, with energy efficiency a prime consideration, refrigeration engineers rely on the properties of CFCs in designing units that provide more cooling with less electric current than was thought possible a few years ago.



Air Conditioning

\$12.9 billion

130,000 jobs

Air conditioning makes the difference between comfort and misery when the weather is hot and sticky, but because we take it so much for granted, many of the other benefits it has brought us may not be evident. Consider:

- Air conditioning in hospitals and nursing homes means a more healthful, comfortable environment, more conducive to healing.
- Air conditioned offices and factories make it possible for people to perform at peak efficiency even in the hottest weather.
- A number of important industries could not operate at all without air conditioning: manufacture of pharmaceuticals and photographic and printing films, computer installations, production of electronic equipment, telecommunications.
- Businesses, theaters, shopping malls, sports arenas now operate successfully year-round, regardless of the climate or weather.
- Air conditioning in cars means not only more comfortable travel, but highway safety studies show it contributes to driving safety by reducing heat stress and fatigue.
- CFCs and air conditioning technology have led to development of energy-efficient heat pumps, solar heat systems and other heat recovery devices.

All these benefits have been made possible largely by CFCs. Air conditioning technology has been based on them, and there are no safe, suitable substitutes.



Plastic Foams

\$2 billion

40,000 jobs

CFCs are important as blowing agents in making insulating, food packaging and cushioning foams out of plastic materials.

Insulating foams made with CFCs have twice the insulating value of fiberglass of the same thickness and also insulate better than foams made with other compounds. The foams are used in refrigerators and freezers, walls and roofs of houses and buildings, refrigerated railway cars and trucks, and in many industrial applications. They save substantial amounts of energy and reduce heating and cooling costs.

Because of the foams' efficiency, insulating walls can be thinner, which saves materials and provides more usable space. The foams' light weight is also a space and energy-saving advantage, particularly in insulated trucks and railway cars.

CFC food packaging foams provide insulating value for hot and cold foods and do not absorb liquids or grease. Foam meat trays are becoming familiar in supermarkets. Foam egg cartons cushion the eggs so there is less breakage than with conventional cartons.

Cushioning foams are rapidly replacing the old spring-and-padding construction of mattresses and upholstered furniture, and the lower cost and greater comfort are boons for the consumer. In cars, airplanes and trains, CFC-blown foams provide superior cushioning in seats and padded areas, such as automobile dashboards.

While other blowing agents are often used for cushioning foams, those made with CFCs provide more softness, resilience and durability.



Cleaning Agents

Products valued in the billions of dollars.

More than 10,000 jobs

As microchips and other components of electronic equipment have become smaller and more sophisticated, the need for absolute cleanliness in manufacturing has become critical. CFCs are the cleaning agents of choice, because they remove the smallest contaminants and leave a clean, dry surface. Also, CFCs are safer to use than other cleaning agents, which are more toxic and/or flammable.

In many other industries as well, CFCs are used as cleaning solvents and degreasers, providing the advantage of thorough cleaning without the volume of wastes generated by water and other solvents.



Food Freezants

\$0.4 billion

More than 500 jobs

The food we eat today is more varied year-round, more nutritious and better tasting than it used to be because of freezing, and CFCs deserve much of the credit. The frozen food revolution was made possible by CFCs, which made refrigerators and freezers safe for home use.

Now, CFC food freezants provide ultrafast, direct contact freezing of many foods that could not be frozen satisfactorily by the usual "air blast" method. CFCs have energy-saving advantages over other freezants, which require up to eight times the energy needed with the CFC system.



Sterilants

\$0.1 billion

More than 500 jobs

CFCs mixed with a sterilizing agent are widely used in hospitals and in the manufacture of medical equipment and devices. The CFCs make the sterilizing agent nonflammable without affecting its sterilizing ability. Gloves, syringes, catheters and tubing, anesthetic and respiratory equipment, pharmaceuticals and other medical supplies are made sterile by these mixtures.

Fumigants, Pesticides CFCs blended with other chemicals are used as fumigants and pesticides in granaries, warehouses and the holds of ships.

CFCs: The Benefits Are Many

The preceding section mentioned many specific ways in which CFCs benefit society.

In sum, CFCs make important contributions in a number of critical areas today:

Public Safety Because CFCs are not flammable, explosive or reactive with other substances and have low toxicity, they are ideal for use in places where substitute compounds might be hazardous to the public.

Public Health A year-round supply of nutritious, healthful foods is dependent to a large extent on CFC refrigerants and freezants. Air conditioning creates more healthful indoor environments. Health care facilities and the pharmaceutical industry would be hard put to operate without the benefits made possible by CFCs.

Energy The efficient heat transfer properties of CFCs save substantial amounts of energy in refrigeration, air conditioning and insulation uses. It has been estimated that a United States ban on CFCs could, after 10 years, mean an annual energy penalty equal to 9-12 billion gallons of fuel oil, due to the forced use of less efficient materials.

The Economy Besides the goods, services, businesses and jobs made possible by chlorofluorocarbons, products based on CFCs are important exports for the United States, contributing strongly to the nation's balance of trade.

Technology The availability of CFCs has led to important technological innovations, such as energy recuperators, hot water heat pumps, a solar heating system, an innovative cleaning system for electronic components, and a promising new method of cleaning coal which dramatically reduces ash and other pollutants when the coal is burned.

**U.S. PRODUCTION OF FULLY HALOGENATED CFCs
MILLION POUNDS**

	<u>CFC-11</u>	<u>CFC-12</u>	<u>CFC-113</u>	<u>CFC-114</u>	<u>CFC-115</u>	<u>Malon 1301</u>
1980	158 ¹	295 ¹	126 ⁴	4.4 ⁴	5.0 ³	5.7 ⁵
1981	163 ¹	326 ¹	126 ⁵	5.3 ³	6.0 ³	7.0 ⁵
1982	140 ¹	258 ¹	126 ⁵	6.2 ³	7.0 ³	8.2 ⁵
1983	161 ¹	299 ¹	126 ⁵	7.0 ³	7.9 ³	9.5 ⁵
1984	185 ¹	337 ¹	150 ⁵	7.9 ³	8.9 ³	10.6 ⁵
1985	176 ¹	302 ¹	161 ⁵	8.8 ³	9.9 ³	11.7 ⁶
1986	202 ¹	322 ¹	175 ⁵	9.0 ³	10.2 ³	12.8 ⁶
1987	223 ²	368 ²	189 ⁵	9.3 ³	10.4 ³	13.9 ⁶

¹ USITC Final Data

² USITC Preliminary Data

³ EPA, Regulatory Impact Analysis, December 1987.

⁴ Rand, Projected Use, Emissions, and Banks of Potential Ozone Depleting Substances, Jan. 1986.

⁵ Hammitt et al, Product Uses and Market Trends for Potential Ozone Depleting Substances, May 1986.

⁶ Estimated from (5)



TESTIMONY
OF
MARILYN I. MONTGOMERY
VICE PRESIDENT AND GENERAL MANAGER
GENETRON PRODUCTS,
ALLIED-SIGNAL INC.

BEFORE A JOINT HEARING OF THE
SENATE SUBCOMMITTEES ON ENVIRONMENTAL
PROTECTION AND HAZARDOUS
WASTE AND TOXIC SUBSTANCES

WEDNESDAY, MARCH 30, 1988

THANK YOU. MY NAME IS MARILYN MONTGOMERY. I AM VICE PRESIDENT AND GENERAL MANAGER OF ALLIED-SIGNAL'S GENETRON BUSINESS UNIT. WE APPRECIATE THE OPPORTUNITY TO SHARE OUR VIEWS WITH THIS COMMITTEE. AS YOU REQUESTED, WE HAVE ATTACHED PRODUCTION FIGURES TO OUR WRITTEN TESTIMONY.

THE REPORTS OF NASA'S OZONE TRENDS ANALYSIS IS NEW AND DISTURBING INFORMATION -- TO CFC PRODUCERS, TO USERS, TO CONSUMERS, AND TO ALL OF US AS CITIZENS CONCERNED ABOUT THE ENVIRONMENT.

ALLIED-SIGNAL HAS NOT YET BEEN PROVIDED WITH THIS NEW DATA FOR OUR OWN REVIEW. WE EXPECT TO RECEIVE IT SHORTLY AND WE WILL EXAMINE IT AS RAPIDLY AS POSSIBLE. WE WOULD LIKE TO THANK DUPONT FOR PROVIDING US WITH THEIR INTERPRETATION OF THE DATA. IT SHOULD HELP US EXPEDITE OUR OWN ANALYSIS.

BUT EVEN WITHOUT THE DATA, ONE MESSAGE COMES THROUGH CLEARLY FROM OUR READING OF THE PRESS REPORTS -- THIS PROBLEM IS A GLOBAL ONE.

TO BE EFFECTIVE, ANY SOLUTION MUST BE INTERNATIONAL IN SCOPE. THE NEW DATA GIVES ALL OF US AN ADDED SENSE OF URGENCY IN WORKING TOWARD THAT GLOBAL SOLUTION.

FORTUNATELY, THE ELEMENTS OF A REALISTIC AND EFFECTIVE SOLUTION ARE ALREADY IN PLACE IN THE FORM OF THE MONTREAL PROTOCOL.

THE PROTOCOL RECOGNIZES OZONE DEPLETION IS AN INTERNATIONAL PROBLEM THAT CAN ONLY BE SOLVED BY WORLDWIDE ACTION. ALLIED-SIGNAL ENDORSES THIS APPROACH COMPLETELY, AND URGES ALL NATIONS WHO HAVE NOT YET RATIFIED THE PROTOCOL TO DO SO QUICKLY. INTERNATIONAL RATIFICATION OF THE PROTOCOL WILL ITSELF PROVIDE THE INCENTIVES NECESSARY TO COMMERCIALIZE THE NEW PRODUCTS NOW UNDER DEVELOPMENT.

HOWEVER, UNILATERAL ACTION TO PHASE-OUT CFC'S WITHOUT REGARD TO OTHER NATIONS CREATES SEVERAL CONCERNS. FIRST, SINCE THE U.S. PRODUCES ONLY ONE-THIRD OF THE CFC'S USED IN THE WORLD, THERE WOULD BE LITTLE, IF ANY, ENVIRONMENTAL BENEFIT. SECOND, WHATEVER MINIMAL ENVIRONMENTAL BENEFITS MIGHT BE ACHIEVED WOULD BE AT THE EXPENSE OF DOMESTIC PRODUCERS, USERS AND CONSUMERS. BECAUSE ALMOST ONE MILLION JOBS IN THE UNITED STATES ARE CFC-RELATED, THIS COULD CREATE SEVERE ECONOMIC DISLOCATIONS. AND THIRD, UNILATERAL ACTION IN THE U.S. MIGHT REMOVE THE INCENTIVE THAT OTHER NATIONS HAVE TO RATIFY THE MONTREAL PROTOCOL.

THIS LAST POINT IS ESPECIALLY IMPORTANT IN VIEW OF THE NEW SCIENTIFIC DATA. IN FACT, WE NEED TO EXERT MORE PRESSURE RATHER THAN LESS TO GET OTHER COUNTRIES TO JOIN IN A TRULY INTERNATIONAL SOLUTION.

THE FINAL SOLUTION OF THIS PROBLEM WILL BE THE DEVELOPMENT OF SAFE, NON-OZONE DEPLETING SUBSTITUTES. WE HAVE INTENSIFIED RESEARCH AND DEVELOPMENT PROGRAMS TO MEET THIS CHALLENGE.

WE FEEL MORE COMFORTABLE IN COMMITTING THE FINANCIAL, TECHNICAL AND HUMAN RESOURCES TO DEVELOP SUBSTITUTES BECAUSE THE MONTREAL PROTOCOL PLACES ALL PRODUCERS - FOREIGN AND DOMESTIC - ON AN EQUAL FOOTING.

REFLECTING THIS COMMITMENT, ALLIED-SIGNAL ANNOUNCED YESTERDAY AN AGREEMENT WITH ATOCHEM, A WHOLLY-OWNED SUBSIDIARY OF FRANCE'S ELF AQUITAINE GROUP, EUROPE'S LARGEST CFC PRODUCER, TO DEVELOP JOINTLY NON-OZONE DEPLETING SUBSTITUTES FOR CFCs. THE AGREEMENT ENCOMPASSES RESEARCH TO DEVELOP PROCESS TECHNOLOGY AND PILOT PLANT CONSTRUCTION LEADING TO FULL-SCALE COMMERCIALIZATION AND THE MORE RAPID INTRODUCTION OF NEW PRODUCTS.

WE ARE EVALUATING HFC-134A AS AN ALTERNATE FOR CFC-12 IN AUTOMOTIVE, AND COMMERCIAL AIR CONDITIONING AND IN REFRIGERATION APPLICATIONS. WE ARE EVALUATING HCFC-123 AND HCFC-141B AS ALTERNATES FOR CFC-11 IN RIGID URETHANE FOAM-BLOWING APPLICATIONS AND IN SELECTED REFRIGERATION APPLICATIONS.

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OVER 30 FULL-TIME SCIENTISTS, PLUS SUPPORT PERSONNEL, ARE INVOLVED IN THE PROJECT AT ALLIED-SIGNAL'S BUFFALO RESEARCH LABORATORY AND AT ATOCHEM'S TECHNICAL CENTER AT PIERRE BENITE, FRANCE.

THE COMPANIES HAVE ALREADY MADE QUANTITIES OF HCFC-123 AVAILABLE TO END-USERS FOR TESTING AND EVALUATION. BY THE END OF JUNE, SUFFICIENT AMOUNTS OF HCFC-141B WILL BE AVAILABLE FOR END-USE TESTING. AND DURING THE FOURTH QUARTER OF THIS YEAR, SIMILAR QUANTITIES OF HFC-134A WILL BE ON HAND.

BOTH COMPANIES ARE CHARTER MEMBERS OF THE PROGRAM FOR ALTERNATE FLUOROCARBON TESTING (PAFT). PAFT IS A COOPERATIVE TOXICOLOGY TESTING PROGRAM INITIATED IN JANUARY 1988 BY 14 INTERNATIONAL CFC PRODUCERS. PAFT HAS BEGUN WORK IN TESTING CFC ALTERNATES TO ENSURE THEY POSE NO THREAT TO HUMAN HEALTH. THE FULL RANGE OF REQUIRED TESTS SHOULD TAKE FROM FIVE TO SIX YEARS -- ASSUMING ALL GOES WELL.

UNDER NORMAL CIRCUMSTANCES, THE DEVELOPMENT OF A NEW PRODUCT FROM THE INCEPTION OF PROCESS RESEARCH TO THE INITIATION OF COMMERCIALIZATION REQUIRES 7-10 YEARS. THERE ARE THREE DISTINCT SETS OF ACTIVITIES WHICH OCCUR DURING THIS TIME PERIOD.

A) LABORATORY PROCESS RESEARCH - DURING THIS INITIAL PHASE OF ACTIVITY, ALTERNATE CHEMICAL ROUTES TO THE NEW PRODUCT ARE FIRST IDENTIFIED AND THEN COMPARED BY SYNTHESIZING THEM ON A SMALL SCALE. DURING THIS PHASE, CONSIDERATION IS GIVEN TO MINIMIZING THE NUMBER OF STEPS NECESSARY TO PRODUCE THE NEW PRODUCT, MAXIMIZING THE YIELD AND REDUCING THE NUMBER OF BY-PRODUCTS FORMED.

THIS PHASE USUALLY LASTS ABOUT 2-3 YEARS.

B) PILOT PLANT - DURING THIS PHASE, THE SELECTED PROCESS IS PRACTICED ON A LARGER SCALE THAN IN THE LABORATORY TO INCREASE CONFIDENCE IN ITS COMMERCIAL FEASIBILITY. PRODUCT PURITY AND BY-PRODUCT HANDLING AND DISPOSAL ARE KEY OBJECTIVES.

THIS PHASE, INCLUDING PILOT DESIGN AND CONSTRUCTION, USUALLY REQUIRES 2 - 2 1/2 YEARS.

C) COMMERCIALIZATION - CONSTRUCTION OF A COMMERCIAL FACILITY GENERALLY BEGINS ONLY AFTER THE PILOT PLANT OPERATION IS SUCCESSFULLY DEMONSTRATED, AND ONLY WHEN CHRONIC TOXICITY STUDIES ARE NEAR COMPLETION. PLANT START-UP USUALLY TAKES SEVERAL MONTHS. AN ELAPSED TIME OF 2 1/2 - 3 YEARS IS NOT UNUSUAL FOR THIS PHASE OF THE OPERATION.

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ALLIED-SIGNAL IS CURRENTLY OPERATING ON AN ACCELERATED SCHEDULE FOR ALL THREE SUBSTITUTES.

OUR PROJECTED SCHEDULE TELESCOPES ALL OF THE STEPS. PILOT PLANT CONSTRUCTION PARALELLS LABORATORY WORK. THIS PRESENTS CONSIDERABLE RISK BECAUSE THE PROCESS CHEMISTRY HAS NOT YET BEEN FULLY DEFINED. FULL PLANT DESIGN AND CONSTRUCTION WILL BEGIN BEFORE THE PROCESS HAS BEEN COMPLETELY DEMONSTRATED, AND CONSIDERABLY BEFORE CHRONIC INHALATION TEST RESULTS ARE COMPLETE. THIS SCHEDULE LEAVES LITTLE ROOM FOR ERROR. BOTH THE TECHNICAL AND FINANCIAL RISK INCREASE SIGNIFICANTLY COMPARED TO THE NORMAL TIMETABLE FOR COMMERCIALIZATION. ACCELERATED COMMERCIALIZATION MOST LIKELY WILL IMPOSE A MANUFACTURING COST PENALTY, AT LEAST IN THE EARLY YEARS OF OPERATION.

SUBSTITUTES FOR CFC-113 ARE IN A MUCH EARLIER STAGE OF DEVELOPMENT. WE HAVE A VERY ACTIVE PROGRAM TO IDENTIFY NON-OZONE DEPLETING SOLVENTS. WE ARE ALREADY OFFERING BLENDS OF CFC-113, WHICH REDUCE THE AMOUNT OF FLUOROCARBONS USED IN CLEANING BATHS FOR PRINTED CIRCUIT BOARDS. WE ARE ALSO DESIGNING NEW EQUIPMENT, INCLUDING RECYCLE AND RECOVERY SYSTEMS, CAPABLE OF HANDLING THE BOILING POINTS OF POTENTIAL SOLVENT SUBSTITUTES. WE PLAN MARKET INTRODUCTIONS IN THE NEAR FUTURE.

WE AS PRODUCERS, KNOW WE ARE DOING AS MUCH AS WE CAN AT THIS POINT TO REACH A WORKABLE SOLUTION AS RAPIDLY AS POSSIBLE. WE KNOW THAT NON-OZONE DEPLETING SUBSTITUTES WILL BE THE SOLUTION. WE BELIEVE THE INTERNATIONAL APPROACH TAKEN BY THE MONTREAL PROTOCOL IS THE CORRECT ONE.

BUT A PROBLEM REMAINS. AND IT IS A SERIOUS PROBLEM. TO DATE, ONLY THE UNITED STATES AND MEXICO HAVE FORMALLY AGREED TO THE PROTOCOL. ALL OF US NEED TO WORK TO GET AS MANY NATIONS AS POSSIBLE TO RATIFY THE PROTOCOL AS QUICKLY AS POSSIBLE. WE RECOMMEND A U.S. DIPLOMATIC INITIATIVE TO THIS END.

THE NEW SCIENTIFIC DATA ON GLOBAL OZONE DEPLETION IS SIGNIFICANT. IT CAN PROVIDE AN ADDED IMPETUS TO OTHER NATIONS TO JOIN IN THE PROTOCOL QUICKLY. TO GET THIS DONE, WE URGE THAT THE UNITED STATES CALL FOR AN IMMEDIATE REVIEW OF THIS NEW DATA BY SCIENTISTS WHO WORKED ON THE DEVELOPMENT OF THE PROTOCOL. THE REVIEW PROVISIONS OF THE PROTOCOL CAN, AND SHOULD, BE ACCELERATED TO DETERMINE WHAT FURTHER ACTIONS MAY BE NECESSARY.

ALMOST EVERYTHING IS NOW IN PLACE TO SOLVE THIS PROBLEM IN A PRACTICAL AND TIMELY WAY. FORMAL ADOPTION OF THE PROTOCOL BY THE WORLD COMMUNITY IS OUR LAST CHALLENGE. IT IS A BIG CHALLENGE. BUT IT IS ONE ALL OF US MUST WORK TO ACHIEVE IF WE ARE TO HAVE ANY REAL SOLUTION AT ALL.

U.S. - PRODUCTION OF CFC'S
(MILLIONS OF POUNDS)

	<u>CFC 11</u> ⁽¹⁾	<u>CFC 12</u> ⁽¹⁾	<u>CFC 113</u> ⁽²⁾	<u>CFC 114</u> ⁽³⁾	<u>CFC 115</u> ⁽³⁾
1980	155.1	282.8	126.0		
1981	162.7	325.5	126.0		
1982	140.3	258.0	126.0		
1983	161.4	298.1	126.0		
1984	184.9	336.6	150.0		
1985	175.9	302.0	161.0	8.8	9.9
1986	202.6	322.9	174.0		
1987	223.4 ⁽⁴⁾	368.4 ⁽⁴⁾	190.0		

1) U.S. INTERNATIONAL TRADE COMMISSION REPORTS

2) ESTIMATED BASED ON AVAILABLE RAND DATA

3) FROM EPA ESTIMATES

4) PRELIMINARY ITC DATA



*Natural Resources
Defense Council*

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**CFCs AND HALONS:
NEXT STEPS TO A TOTAL PHASE-OUT**

Testimony of

**David D. Doniger, Senior Attorney
Natural Resources Defense Council**

**before the
Hazardous Waste and Toxic Substances Subcommittee
and the
Environmental Protection Subcommittee
of the
Senate Environment and Public Works Committee**

March 30, 1988

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In the past two weeks, we have witnessed two extraordinary events in the long struggle to protect the stratospheric ozone layer. The first was the alarming finding by the Ozone Trends Panel, made up of more than 100 scientists, that the ozone layer is already suffering severe and unexpectedly rapid depletion all over the globe, with chlorofluorocarbons (CFCs) the likely cause. The second was the announcement by E.I. du Pont de Nemours & Co., the world's largest CFC producer, of its conversion from staunch opponent to public supporter of a CFC phase-out and an early tightening of the Montreal Protocol.

These events have fundamentally transformed the public debate on protection of the ozone layer. We have finally achieved consensus that we face a global emergency, though at the price of committing the world to enormous human health and environmental damage over the coming decades. A phase-out of CFCs and other ozone-depleting chemicals was regarded as a radical notion when NRDC first proposed it two years ago. A phase-out is now mainstream thinking.

But obviously it is still just an proposal, not an accomplishment. Sometime in 1943, General Eisenhower must have sensed he was going to win the war, but he knew there were many steps to be taken before the victory was real. That is where we stand on ozone depletion. The task before us all is to bring the phase-out to reality.

And this task must be accomplished as rapidly as possible. It is not alarmist to call our situation a global emergency.

There is no longer any doubt about the inadequacy of the Montreal Protocol and the regulations proposed by EPA. We've already suffered more ozone depletion than EPA predicted would occur under the Montreal agreement and the EPA regulations by the year 2050. In their present form they will not stop depletion, only slow its acceleration. Merely to stabilize the atmospheric stockpile of chlorine at its present level requires at least an 85 percent cut in CFC use. Actually cleansing these chemicals from the atmosphere requires a total phase-out. Even then, recovery of the atmosphere will take a century or more; the damage to public health and the environment will continue for four generations or longer.

So what shall we do next to capitalize on the breakthroughs of the last two weeks? I believe these are the necessary next steps:

- o The entire CFC and Halon industry, producers and users alike, both here and abroad, must be pressed to take the phase-out pledge. That pledge should contain specific deadlines for action (which are absent from du Pont's) and specific measures that will be taken to obtain the support of industry in all countries for early ratification and immediate reassessment of the Protocol.
- o Secretary of State Shultz should make it a top U.S. foreign policy objective to achieve ratification of the Montreal Protocol by the European nations, Japan, and the U.S.S.R. within the next three months. The Secretary of State, and the President, should make it clear to our allies that the U.S. expects ratification, plus support for early reassessment, prior to the seven-nation economic summit in June.
- o The U.S. should call for, and the United Nations Environment Programme should schedule, an immediate reassessment of the Montreal Protocol. The scientific review should commence this summer, and negotiators

should be reconvened in January or February, right after the Protocol is scheduled to take effect.

- o The EPA must carry out its obligations under the Clean Air Act, which will not be satisfied by a 10-year half-way measure. The Act requires regulation of domestic CFC and Halon usage to the extent necessary to protect the stratosphere, not merely to the extent called for by an international agreement now conceded to be inadequate. EPA should accompany domestic phase-out requirements with trade provisions like those proposed in the legislation before this Committee to protect U.S. industry and leverage cooperation from our major trading partners.
- o The EPA should establish a CFC and Halon production fee to prevent du Pont, Allied-Signal, and a handful of other producers from reaping monopoly profits off the sale of CFCs as supplies are limited. These windfall profits could range from \$2 billion to \$6 billion over the coming decade. It is unthinkable that the very companies responsible for damaging the ozone layer should reap windfall profits from a phase-down.
- o Congress should not leave protection of the ozone layer to the Executive Branch. In addition to holding hearings, this Committee can help in two other concrete ways. First, you can continue pressing industry, the Administration, and UNEP for the actions I am describing. Second, you should immediately move S.570 and S.571 into law. You should not leave the job to EPA, in this Administration or any other. The picture is clear enough for Congress to act itself to phase out CFC and Halon usage, establish an appropriate production fee, and implement the necessary trade provisions.

Industry: Pledge a Rapid and Complete Phase-Out

NRDC welcomes du Pont's announcement, in the wake of the new scientific evidence, of its support for phasing out fully halogenated CFC production, and for swift ratification and immediate strengthening of the Montreal accord. For the world's largest producer of these chemicals to recognize that their use must be ended is an important step forward.

Not that this announcement can compensate for the global damage that du Pont, or any other member of the industry, has done. As put by the Washington Post in an editorial on March 27: "It's hard to know quite how to react. The new position is laudable; the old may turn out to have been disastrous." Nothing can excuse du Pont's role in the industry's long history of denial and intransigence in the face of ever-increasingly strong scientific evidence. Nothing can justify the unparalleled arrogance of even having taken a chance with the safety of the ozone layer, with the health and welfare of hundreds of millions of people, with the integrity of crucial ecosystems, and with the stability of the climate itself.

And not that the announcement of a phase-out "goal" is sufficient. Du Pont has given no specific schedule for ending production. The global emergency warrants a crash program; we believe that with such a program a phase-out can be completed in six to eight years. We call on du Pont to join in this schedule.

But as I said last week, a late conversion is better than no conversion at all. And however belated the conversion, it is the first in the industry.

The task now for each other producer and user of ozone-depleting chemicals is to follow du Pont and take the phase-out pledge. In the coming weeks, NRDC will be seeking such commitments from each other producer and each major user of CFCs and Halons in the United States. In conjunction with environmentalists in Europe, Japan, and elsewhere, we will seek

similar commitments from industry abroad. We will ask American firms to undertake specific reduction schedules, to press their foreign counterparts to do the same, and to press them to support early ratification and immediate strengthening of the Montreal Protocol.

In addition to making an eventual phase-out, we will also ask major users to make short-term reductions. In this country, for instance, users of CFCs in foam food packaging are on the verge of an immediate move away from fully-halogenated compounds. Other nearly immediate economies in CFC use can be made by other foam users, by the auto industry (recycling of auto air conditioning refrigerants), and by the electronics industry (recycling and substituting solvents), by hospitals (reducing CFC use as a sterilant), and by many other sectors.

Abroad, the American government, environmentalists, and industry alike should join in demanding an immediate end to the use of CFCs in aerosols. Approximately 27 percent of world CFC use is still in this utterly frivolous application that the U.S. banned 10 years ago. Industry in other countries should be urged to ban aerosols voluntarily, even in advance of supply restrictions under the current Protocol.

State Department: Achieve Allied Ratification by the Economic Summit

It is unacceptable that there is still doubt whether a sufficient number of parties will ratify the Montreal Protocol in time to bring it into effect as scheduled on January 1, 1989. While preparations for ratification are said to be underway in

the countries of the Common Market, in Japan, and in the Soviet Union, as of now only Mexico and the U.S. have ratified. The United States is in a position to exert great leverage on these countries. After all, they are, with one exception, our allies. They have signed. They have taken the credit. Now they must perform.

The Secretary of State needs to elevate ratification by these countries to the very top of his foreign policy agenda. Unfortunately, the matter still lingers at the level of environmental agencies in other countries. Mr. Shultz should make it clear to his counterparts in Western Europe and Japan that the President considers ratification of the Protocol, plus support for immediate reassessment of its terms, an absolute prerequisite before the seven-member economic summit in June.

EPA/State Department/UNEP: Establish a Definite Schedule for Reassessment of the Protocol

Press reports yesterday indicate that EPA Administrator Thomas will shortly be writing UNEP executive director Tolba requesting that a science review begin this fall, in preparation for an early diplomatic reassessment of the Protocol's reductions. While this is a helpful step, it is unfortunate that Mr. Thomas apparently is not suggesting a specific date for the diplomatic meetings to begin.

I submit that we cannot afford any delay. The U.S. should call for, and the United Nations Environment Programme should schedule, an immediate reassessment of the Montreal Protocol. The scientific review should commence this summer, and

negotiators should be reconvened in January or February, right after the Protocol is scheduled to take effect.

It has been argued that so early a review might cause some other countries to balk at ratification. I believe it is too late for that. Virtually all of these countries have already signed. Moreover, ozone depletion is now certifiably occurring right over their heads, not in some far off place at the South Pole. They cannot bear to be perceived to renege now.

EPA: Carry Out the Clean Air Act's Mandate for CFC and Halon Controls Responsive to the Danger

In December EPA proposed regulations to control CFCs and Halons; final regulations are due on August 1 under a court order obtained by NRDC. The proposed rules precisely mirror the requirements of the Montreal Protocol. They go no further than Protocol-level reductions, and even these will not take effect until and unless the Protocol enters into force.

By basing its proposal not on what is environmentally necessary, but merely on the requirements of the Protocol, EPA is violating the Clean Air Act. Section 157(b) gives EPA no authority to defer to international agreements or negotiations. Nothing in the legislative history says that EPA may delay or weaken regulations required by findings of effect on the stratosphere and endangerment to health and environment in order to wait for or be consistent with an international agreement.¹

¹ Section 157(b) requires EPA to issue regulations over domestic production and use when the Administrator determines that "any substance, practice, process, or activity (or any combination thereof)" "may reasonably be anticipated to affect" the

To the contrary, Section 156 provides that the State Department shall seek international control agreements "consistent with" U.S. domestic regulations, not vice-versa.² The science compels a phase-out of domestic emissions, independent of the need for a world-wide phase-out. That is what EPA is required to accomplish under the Clean Air Act.

EPA has asserted that U.S. leadership in making reductions might discourage action by other countries. To the contrary, there is ample evidence that U.S. leadership encourages action by other countries. U.S. concern over ozone depletion by CFCs has always been the engine driving things forward. U.S. leadership was essential to achieving the limited reductions contained in the Montreal Protocol.

In addition, EPA has authority under §157(b) and other laws to leverage cooperation from other countries, as well as to protect domestic industry from unfair foreign competition. EPA can do this by conditioning the right of other countries to

stratosphere, including the ozone layer, and that "such effect may reasonably be anticipated to endanger" public health or the environment. Section 157(b) require EPA to consider specified research and studies and consult with "appropriate Federal agencies" when writing regulations, but it does not make treaties or other agencies' views the measure of the necessary action.

² Section 156 states that the President, through the State Department, "shall undertake to enter into international agreements . . . and to develop [international] standards and regulations which protect the stratosphere consistent with regulations applicable within the United States." Discussing this provision, the Senate Report states that international cooperation in research and regulation is "encouraged" but suggests no limit on EPA's obligation to regulate domestic emissions.

import CFC-containing and CFC-derived products into the U.S. on their agreement to making parallel reductions.³ The fact that only some other countries followed the U.S. lead in banning aerosols is sometimes used as an argument against U.S. leadership. But in that case the U.S. made no effort to use trade conditions to exert leverage abroad.

Besides independantly leveraging reductions abroad, such a measure would encourage the agreement of other countries to an early strengthening of the Protocol; as Ambassador Benedick pointed out in the Washington Post on January 4, the threat of unilateral action coupled with trade restrictions was instrumental in securing the agreement of hard-line countries to the current agreement. The promulgation of such restrictions in the U.S. regulations now would help secure agreement to strengthen the protocol in light of the new science.

So if coupled with an appropriate trade condition, U.S. leadership in making earlier or deeper reductions than those required by the protocol would encourage, not discourage, additional reductions abroad.

³ Such restrictions could be established under the Administrator's authority under §157(b) to "control" any "substance, process, practice, or activity." These words can easily be construed to cover the practice or activity of importing CFC-containing or CFC-derived goods into the U.S. The U.S. Trade Representative has ruled that such a measure would comply with the GATT and other international trade laws if, as here, it has a sound health and environmental justification.

EPA: Prevent Producers from Reaping Windfall Profits

The proposed regulations assign production and consumption privileges to current producers and importers of CFCs and Halons. There are only five domestic CFC producers and only a handful of importers. The number of Halon producers and importers is similarly limited.

Production limitations are an essential part of the regulatory scheme. But alone they have two very undesirable drawbacks. First, they create a kind of OPEC for CFCs and Halons. Giving production and consumption privileges to this small number of producers and importers would give them windfall monopoly profits ranging from \$2 billion to \$6 billion over the coming decade, according to EPA. There is no reason in the world why any portion of the industry -- especially the companies responsible for damaging the ozone layer to start with -- should reap a windfall profit from a phase-down.

The producers have claimed they need these funds to develop alternative chemicals. It is difficult to imagine a need for \$2-6 billion for such purposes, however. The alternatives promise to be quite profitable and thus should be able to attract the necessary capital from normal internal or external sources.

Moreover, the lure of windfall profits may cause producers to delay the introduction of, or increase the price of, alternative chemicals. The motive for doing this would be to maximize the joint profits of selling both conventional and alternative chemicals. A producer would schedule its R&D and the

introduction date and pricing for a new product according to a calculation of how it can maximize its total profits.

The most attractive way to prevent the rules from unjustly enriching the producers or interfering with their incentives to produce alternatives is, as proposed in S.570, to impose a fee on the sale of CFCs and Halons, on a per-pound basis, as a supplement to production and consumption limits. In our view, EPA can and should do so under the existing Clean Air Act as well.⁴

Congress: Press the Executive Branch for Action and Enact CFC and Phase-Out Legislation

Congress should not leave protection of the ozone layer to the Executive Branch. In addition to holding hearings, this

⁴ In 1976 the Supreme Court upheld the use of license fees to accomplish a similar objective of restraining oil imports, under statutory language strikingly similar to that in §157(b). The Court upheld President Ford's imposition of license fee on imported oil under the Trade Expansion Act of 1962 (as amended). Federal Energy Administration v. Algonquin SNG, Inc., 426 U.S. 548 (1976). The case provides authority for an EPA-instituted fee under §157(b).

Under the Trade Expansion Act, if the Secretary of the Treasury finds that "an article is being imported into the United States in such quantities or under such circumstances as to threaten to impair the national security," the President is authorized to "take such action, and for such time, as he deems necessary to adjust the imports of [the] article so that . . . imports of [the article] will not threaten to impair the national security." The Court upheld "quantitative methods -- i.e., quotas -- [as well as] monetary methods -- i.e., license fees -- of effecting such adjustments." *Id.* at 561.

Section 157(b) provides for "regulations" for "control" of "any substance, practice, process, or activity" affecting the ozone layer. This very general language, atypical of more common command-and-control provisions, closely parallels that of the Trade Act. Monetary devices were accepted under the FEA case; they should pass muster here too.

Committee can help in two other concrete ways. First, you can continue pressing industry, the Administration, and UNEP for the actions I am describing:

- Ask each U.S. producer and user of CFCs and Halons, as well as their foreign counterparts, to make a specific pledge to phase out these chemicals.

- Press the Secretary of State and the President to make early ratification and immediate reassessment of the Protocol a high priority matter for the June economic summit.

- Demand that EPA carry out a phase-out and implement a windfall profits fee within the Clean Air Act regulations due on August 1.

Second, you should immediately move S.570 and S.571 into law. You should not leave the job to EPA, in this Administration or any other. The picture is clear enough for Congress to act itself to phase out CFC and Halon usage over six to eight years, establish an appropriate production fee, and implement the necessary trade provisions.

* * *

Look at where we are. The world is committed to 100 years of ozone depletion; to millions of cases of skin cancer and other disease; to untold damage to the environment and climate. We've waited 15 years too long to end use of these chemicals.

Yet it will be even worse unless we act now. There is the basis, for the first time, for a broad consensus among government, environmentalists, and industry on a rapid, complete phase-out. If we take the steps I have outlined above, we may be able to achieve a new world-wide agreement in as little as a year, and to end these chemicals' use by the end of the century.

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